Forest Products Research 1959

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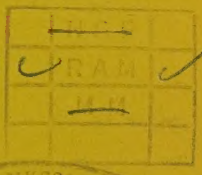

DEPARTMENT OF
SCIENTIFIC AND INDUSTRIAL RESEARCH

FOREST PRODUCTS RESEARCH 1959

Report of the Forest Products Research Steering Committee with the Report of the Director of Forest Products Research

LONDON
HER MAJESTY'S STATIONERY OFFICE
1960

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1959

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REPORT OF THE FOREST PRODUCTS RESEARCH STEERING COMMITTEE FOR 1959

To the Council for Scientific and Industrial Research

THE formation of the Steering Committee was announced briefly in the annual report of the FPRL for 1958; our first report covers the period from October 1958, when we held our first meeting, until the 31st December 1959.

During this period we have concentrated much of our attention on the research and development requirements of the timber industries, from production to use, and on the future functions of the Laboratory, particularly in relation to the responsibilities of the Timber Development Association.

We have felt the necessity for a clearer definition of the functions of the Laboratory and the part it should be expected to play in the national programme of research. We submitted our views to the Research Council who have agreed to the following general statement of future policy for the Forest Products Research Laboratory:

> There is a continuing need, in the national interest, both for research of a fundamental character on timber (but with ultimate practical applications) and for work of immediate benefit to the Forestry Commission and timber users. This work is best done at the Forest Products Research Laboratory, with financial support from industry wherever possible. The Laboratory's programme should be co-ordinated with that of the TDA and any research association concerned but should primarily be devised to ensure that the interests of Government and the whole timber industry are served to the best advantage.
>
> This should provide sufficient flexibility to accommodate the legitimate interests of others concerned with the same general field while maintaining a viable research organization at the Laboratory with freedom to range widely if the need should arise.

Our policy is to foster a deep attack on the basic sciences underlying the problems of timber, and at the same time to maintain close contact with the practical problems of industry. Experience elsewhere suggests that this is the most fruitful approach and that the neglect of either aspect can lead to waste and disappointment. Our task would be made easier, however, if there were more research done, and a greater appreciation of its value, in the component firms of industry: and this is a matter which we shall pursue.

We understand that the TDA is putting forward proposals for setting up a research association. The Committee regards this as a very important step forward and hopes that such an Association would be able to assume considerable responsibility for many aspects of timber research.

The main recent development in the work of the Laboratory has been a great increase in the scope and size of the investigations carried out for the

Forestry Commission on home-grown timber; the Commission considers that its research requirements are likely to increase further during the next few years. These investigations are designed to assist the Commission in deciding both its future planting policy and the most economic way of using its timber. We were glad to be able to discuss the Forestry Commission requirements, and the way in which the Laboratory could help, with Sir Arthur Gosling, Director General of the Commission.

As part of the programme for the Forestry Commission, the Laboratory started pulping investigations in the late Autumn. We are grateful to the Tropical Products Institute for the training given to members of the staff of this section, and particularly indebted to the Norwegian Pulp and Paper Research Institute which, following our request for assistance, sent one of its senior staff to FPRL to advise on the research programme for the group. Mr. Dahm, the officer concerned, attended one of our meetings during his stay at the Laboratory and discussed the programme with us. Whilst home-produced pulp cannot be expected to compete with imported pulp for the majority of paper requirements, the prospects for certain quality papers based on a wholly domestic pulp industry are much more promising.

As a result of these arrangements, and of a visit paid to Norwegian laboratories by Dr. Henderson and Mr. Wooldridge, relations with timber and timber products research organizations in Norway have been consolidated on a very cordial basis. We look forward to continued and mutually profitable close co-operation with these bodies, in pulping and in other fields.

B. K. BLOUNT,

Chairman.

REPORT OF THE DIRECTOR OF FOREST PRODUCTS RESEARCH FOR 1959

GENERAL

THE year under review has been noteworthy for two developments — the great increase in projects on home-grown species and the preparations for research into their pulping properties. These two programmes, carried on in collaboration with the Forestry Commission, now constitute a major commitment of the Laboratory.

With regard to the former, the programme on solid timber is under continuous review by a joint standing committee of the Commission and the Laboratory, and their recommendations have resulted in work on projects of practical importance which now absorb 43 per cent of the staff effort and involve every section of the Laboratory. In addition to problems of immediate application, the programme includes longer-term studies on the effect of site and silviculture on the properties of the timbers in the Commission's plantations.

So far as pulping is concerned, the year has been spent in the training of staff at the Tropical Products Institute (where interim testing was already in hand) and in the adaptation of buildings and the assembly of apparatus. In mid-November the first pulping trials of Sitka spruce were started. These tests, which will yield much information on the pulping potentialities of the various home-grown species of different origin and site, will of necessity be largely of a routine type, and it is intended that a programme of supporting fundamental work shall be put in hand as soon as possible. To this end a senior officer of the Norwegian Pulp and Paper Research Institute visited in the autumn to gauge the Laboratory's resources and to discuss and advise on a tentative programme which would at the same time serve as a starting point for the development of the Laboratory's own scheme and yet fit in with work being pursued elsewhere. Thanks are due to the Norwegian Institute for putting their knowledge and experience so freely at the Laboratory's disposal.

The remainder of the year's effort has been devoted to the normal development of the fundamental research programme in all sections, to appropriate industrial work and to technical instruction and liaison. These activities are referred to in more detail in the body of this report.

VISITS ABROAD

The Officer-in-Charge, Wood Structure Section, visited the United States and Canada, primarily to attend the Ninth International Botanical Congress held in Montreal in August. He presided at a session of the Forest Botany Section and presented two papers, by invitation, one on the β-ray method of determining wood density[1] (see page 5) and the other on the phenomenon of juvenility as it affects the structure and properties of wood[2]. He also attended a meeting of

the International Association of Wood Anatomists which was held concurrently with the Botanical Congress. The occasion afforded an opportunity to visit a number of research institutions in the U.S.A. and Canada and to discuss current work in wood structure, particularly in connexion with the Laboratory's programme of research on home-grown timbers and the recent extension of our terms of reference to cover pulping properties.

The Officer-in-Charge, Chemistry Section, visited Germany in October in order to attend the eighth session of the F.A.O. Technical Panel on Wood Chemistry in Wiesbaden. The opportunity was taken to make short visits to the Institut für Cellulosechemie at Darmstadt, a well-known centre for pulp and paper research, and the Chemical Institute of the University of Heidelberg, where Professor Freudenberg and his school have worked for many years on the chemistry of lignin, tannin, and other wood components. Research work in progress at both of these institutes was discussed with members of their staffs.

A senior officer went, at the request of the Government of Nigeria, to that country for three months to advise on the setting up of a timber research laboratory.

PUBLICATIONS AND RECORDS

Nine publications were issued through H.M. Stationery Office during the year, two being new — the Annual Report for 1958 and *Bulletin* No. 44 "Heat Penetration in the Pressing of Plywood" — and the rest revised editions. The latter describes an investigation to determine whether or not the theory of heat conduction in slabs of an ideal material is applicable to the bonding of five foot square plywood in a hot press. The object of the investigation was to gain a knowledge of the rate of heat conduction both for the estimation of optimum pressing times, and for an understanding of the mechanism underlying the bonding of veneers with a synthetic resin glue.

The other Stationery Office publications include the sixth edition of *Bulletin* No. 1, second editions of *Bulletin* 38 and Record 30, and revised editions of four Leaflets. Particulars of these are given in Appendix II, where also are listed twenty-five papers published in the scientific and technical press.

In addition to the above, sixteen reports of less general interest were prepared.

PROGRAMME OF RESEARCH

WOOD STRUCTURE

IDENTIFICATION OF TIMBERS

Good progress has been made with the revision of the Laboratory's microscope card key to the identification of hardwoods, using perforated index cards. The key was originally devised in 1938, since when it has been in constant use, and it has now been completely revised in the light of 20 years' experience and prepared for publication. The work has involved the examination or re-examination of specimens representing about 800 species and the preparation of coded descriptions which have been checked with such other descriptions as have been published. A series of more than 80 photomicrographs, showing the diagnostic features of hardwoods, has also been prepared to illustrate the key.

The first edition of the Laboratory's lens key to hardwoods, *Bulletin* No. 25, which was published in 1952, is now exhausted and the opportunity has been taken to revise the text and bring it in line with the microscope key. The revised edition should be ready for publication early in 1960[3].

To meet the continued demand for *Bulletin* No. 22, Identification of Softwoods, a limited edition has been prepared by photographic reproduction.

STUDIES IN COMPARATIVE ANATOMY

Work under this head has been confined to studies of timbers included in the microscope key to hardwoods, referred to above, and to four timbers received for general laboratory tests, namely, dark red seraya from North Borneo, *Khaya anthotheca* from Ghana, nkobakoba from Uganda and African satinwood from Uganda.

COLLECTION OF TIMBER SPECIMENS

Under long-standing exchange arrangements, a valuable collection of specimens from the Florida Keys, including many rarities, has been received from the Yale University School of Forestry, also a small collection of local timbers from the Forest Department, Sierra Leone. As usual duplicate material has been distributed to various institutions concerned with research or education.

HOME-GROWN TIMBER INVESTIGATIONS

Under the terms of the programme of work for the Forestry Commission a start has been made on the systematic investigation of home-grown Sitka spruce. The scheme for studying the variation in anatomical structure throughout Great Britain involves the evaluation of timber from different sites in terms of its anatomical structure. So far attention has been concentrated on recording the incidence of compression wood, the dimensions of fibres and the inclination of the grain. Considerable exploratory work has been involved in developing standard methods of carrying out the very large number of observations required in the most economical manner. A special instrument has been designed and made for measuring the inclination of the grain in cross-sectional discs. The method is to split the disc in two parts along a diameter and measure the inclination of the split radial surface at intervals from pith to bark.

A separate scheme has been worked out for investigating more intensively the pattern of variation in anatomical structure within the individual tree. The systematic examination of home-grown Sitka spruce in this connexion has not yet been started but basic studies of the progressive changes in structure from pith to bark in timber trees generally have a definite bearing on this project.

Other projects included in the programme are concerned with the evaluation of timber quality in trees of genetical and provenance interest by anatomical methods, using non-destructive methods of sampling standing trees, and the use of anatomical methods for assessing the quality of wood for pulping.

THE β-RAY METHOD OF DENSITY DETERMINATION

In co-operation with the Isotope Division of the Atomic Energy Research Establishment, Harwell, development work on the β-ray method of determining density variation along a strip of wood prepared from an increment boring has been completed and a report published[4]. In this semi-micro method the air-dry sample in the form of a parallel-sided radial strip, 8 mm thick, is scanned in 0·5 mm steps by a collimated beam of β-rays from a strontium+yttrium source.

The relative absorption of the β-rays is a measure of the density of the wood. Comparison of the results with density figures obtained by a gravimetric method on samples dissected from individual growth rings has shown agreement within 2·5 per cent. From theoretical considerations it has been proved that, for any given degree of accuracy, the observation time for the β-ray absorption is independent of the density of the wood, and that an observation period of one minute is sufficient for each determination whether on low-density spring wood or high-density summer wood. This finding simplifies the problem of devising an automatic mechanism for moving the sample across the beam of radiation and recording the observations.

In addition to its use for studying density variation across the growth ring, the β-ray method offers an objective means of measuring the percentage of summer wood. Various methods of determining this characteristic have been used in the past but none are easy to apply and all are liable to personal bias especially when the transition from spring wood to summer wood is gradual. Mork's method of defining the boundary between the two zones is based on an arbitrary value of the ratio of the thickness of the tracheid wall to the width of the lumen. Wood is classed as summer wood when the common wall between two tracheids is equal to or wider than half the lumen[5]. On the curve showing the variation in density across the growth rings, obtained by the β-ray method, a line is drawn parallel to the abscissa at a density value corresponding to the lower limit for summer wood as determined by Mork's method (see Plate 1). The intercepts on the curve then give a measure free from errors of personal observation of the amount of summer wood. This method should provide strictly comparable observations whether the material is drawn from adjacent growth rings in the same sample or from different trees or even from entirely different species. A paper incorporating a description of this new application of the β-ray method was presented at the Ninth International Botanical Congress held at Montreal in August 1959[1].

SEASONING

KILNS AND KILN SEASONING

The large kilns have been used for seasoning consignments of abura, afrormosia and Japanese oak, in addition to which a number of Uganda timbers were kiln-dried at the request of the Crown Agents. These latter timbers are to be used in the construction of a decorative screen in the Parliament building at Kampala and consisted of the following species:—munyama, mvule, nkoba, loliondo, *Podocarpus* sp. and mumuli. The last named timber, in particular, required careful treatment in the kiln since it tended to dry slowly and it was split on arrival.

In the intermediate kilns, consignments of oak, walnut and Japanese oak have been dried and, in the miniature kilns, the seasoning properties of *Shorea waltoni*, *Khaya grandifoliola*, and home-grown Turkey oak have been examined.

Standard seasoning runs have been carried out to determine the seasoning properties of home-grown Sitka spruce from fifteen different sites. A system of allocating marks for the various forms of seasoning defects has been devised so that a seasoning index figure can be obtained for each of the test runs, thus permitting comparisons to be made on a statistical basis which has not hitherto been attempted. A large number of runs has also been undertaken in the small kilns to determine the optimum drying schedule for this material.

AIR DRYING OF SITKA SPRUCE

In order to determine the effect of locality on the rate of drying and general behaviour of home-grown Sitka spruce piled for air seasoning, experimental piles of 1 in. and 2 in. fresh sawn material were erected at (a) Culloden, Inverness-shire, where the average rainfall is about 27 in. and (b) Strachur, Argyllshire, where the average rainfall is about 90 in.

The first piles which were put up in early March were covered with corrugated iron roofs. The average moisture content of the 2 in. material reached a value of 25 per cent after periods of 43 and 38 days at Culloden and Strachur respectively and the 1 in. material attained the same degree of dryness in periods of 35 and 22 days.

Dry weather conditions prevailed during much of the spring and summer and these apparently favoured the drying at Strachur even more than at Culloden. New and similar piles were erected in early October on the same sites and, in addition, an uncovered pile of 2 in. material was built at Strachur to compare the drying rates of piles with and without roofs.

TWIST IN SITKA SPRUCE

As a consequence of the experimental work carried out to determine the seasoning properties of home-grown Sitka spruce, an interesting finding emerged, namely that boards containing the heart (quarter-cut) tended to twist during drying more than similar boards cut from nearer the outside of a tree (slash-cut) and that the twist was always in one direction. To give an example, it was found that the average twist of twenty quarter-cut boards 1 in. in thickness from a consignment dried from the green to 8 per cent moisture content was about 5 degrees on a length of 2 ft, whereas the corresponding slash-cut boards showed a twist when similarly dried of only $1\frac{1}{2}$ degrees. The near end of a board viewed from that end was observed always to have twisted in a clockwise direction relative to the more remote end.

The causes of the development of this twist were made apparent when a number of trees were examined and it was found that the grain in each tree spiralled around the pith. The tendency to twist varies directly as the shrinkage and as the angle of spirality of the grain, but inversely as the distance outwards from the pith. Thus, for a given angle of spirality, the angle of twist for a unit of length in a tree of small diameter would tend to be greater than in a tree of larger diameter dried through the same moisture content range. Moreover, the tendency to twist of consecutive annual rings from the pith to the outside would decrease with distance outwards, thereby inducing a complicated system of internal stressing.

The relationship between the angle of spirality of the grain and the lateral shrinkage of Sitka spruce was examined in the following manner. Tubes 7 in. in length having an inside diameter of $1\frac{1}{4}$ in. and an outside diameter of $1\frac{3}{4}$ in. were turned from short lengths of logs in such a way that the initial position of the pith became the position of the axis of each tube. The angle of spirality was measured on the inner and outer surfaces and each tube thoroughly conditioned in air at 77°F temperature and a humidity of 30 per cent. After conditioning, each tube was measured at four points across its diameter and then a steel pointer was fitted across one end. The other end was secured in position on a metal framework designed so that the tip of the pointer at the other end came into contact with a graduated scale. The framework with tubes in position was

moved into steady air conditions of 77°F and 90 per cent humidity and left there to become fully conditioned. The end of each tube with the pointer attached was free to rotate relative to the secured end and the extent of such movement could be read at any time along the scale. The average lateral dimensional changes could be determined from further measurements of the diameter. It was clearly demonstrated that the spirality is a major factor in the development of twist as a consequence of moisture change. The values for the angle of twist actually recorded were, however, not always in good agreement with those calculated from a simple formula, relating twist to grain angle, shrinkage and radius, which had been worked out from purely geometrical considerations. The apparatus used for these tests is depicted in Plate 2.

Having determined the nature of the factors causing twist to occur when home-grown Sitka spruce is seasoned, consideration was given to methods of minimizing or eliminating this particular form of degrade. Obviously the problem would be satisfactorily solved were it possible to grow trees in which the grain everywhere was straight and parallel with the pith. It may be possible by a careful selection of seed provenance and the application of breeding techniques to produce trees that contain straight grained timber, but clearly this would be a very long-term project.

One immediate method to reduce the tendency for sawn material to twist would be to exclude the heart or central portions of the log since these exhibit the greatest distortional tendencies. This method, however, would drastically curtail the output of sawn material, particularly of the thicker dimensions that are now obtained from thinnings and trees of relatively small girth measurements.

A method that appeared to offer some promise of immediate improvement was to induce mechanically a twist in the material to be dried approximately equal and opposite to the inherent twist. An experiment was carried out on these lines on a parcel of 2 in. thick material of lengths varying between 9 ft and 14 ft which was dried from the green in the Laboratory's large cross-shaft type kiln to a final moisture content of about 17 per cent. The mechanically imposed twist was induced by piling the load on a foundation that was built with a left-handed twist of some 7 degrees in a length of 14 feet. The wood was piled on this distorted foundation in the normal manner and when finally the pile was completed, pressure was applied by steel joists placed at intervals across the top connected at their ends to supporting joists beneath the load by means of steel straps and telegraph screws. Some weight in the form of concrete blocks on top was also added. The general arrangement of the clamped load is shown in Plate 3. As the timber dried, the telegraph screws had to be tightened from time to time to take up the shrinkage that occurred, but this was a relatively simple operation.

Simultaneously, in another kiln a load of similar material was dried in the normal manner on a flat base and with only some concrete blocks placed on top of the load to inhibit somewhat the distortion of the upper layers. The drying schedule employed was in the two cases identical, but a final softening treatment at a temperature of 180°F and a humidity of 96 per cent was given to the clamped load for a period of 24 hours just before concluding the run. Both kilns were unloaded after cooling and some 48 pieces from each load were bulk-piled in a polythene container and left for two to three weeks before the final measurements were taken. Any tendency for the wood to "creep" had practically disappeared after that period of time. The mean angle of twist on a 9 ft length

of the restrained material disregarding the direction of twist was 1·43 degrees. The mean angle of twist measured on the same length of the unclamped material was 5·04 degrees.

SWELLING PRESSURES

Tests to determine the pressure exerted by wood when wetted up under restraint have been continued using a modified apparatus which could be moved from one set of air conditions to another.

The pressures exerted by beech blocks conditioned to 11 per cent clamped in the tangential direction and then exposed to 20 per cent equilibrium moisture content conditions rose to maxima similar to those of the blocks wetted in water but at a slower rate. The subsequent rate of decrease was also slower. Values recorded on blocks of Scots pine were less than half those on beech, but they were slightly higher on oak than on beech.

Tests are being conducted to determine the effect of preliminary steaming on the pressures exerted by specimens of beech.

MOISTURE CONTENT AND SPECIFIC GRAVITY OF FRESHLY FELLED CONIFERS

This investigation, forming part of the joint research programme with the Forestry Commission, has been extended to cover seven species grown in all parts of the country. By the end of October over six thousand samples, mainly from Scotland, had been tested. The results of this work will help to assess the yield of pulp that can be obtained from given quantities of softwood from given areas. Supplementary tests to examine the fluctuation of moisture content with time of year have been started.

WOOD BENDING

SOLID BENDING

The steam bending properties of two more consignments of English ash have been examined and standard tests completed on mutenye, *Khaya anthotheca* from Uganda and four home-grown softwoods. Tests have also been carried out on a consignment of Turkey oak to determine its bending properties.

Methods of softening and setting bentwood by radio frequency heating have been compared with the usual standardized method of softening by steam and setting by drying in a heated chamber. The latter method is generally to be preferred though bends of large radii of curvature appeared to set better in the radio frequency field than in the heated room.

LAMINATED BENDING

Work in this field has been confined mainly to determining the breaking radius of various species and thicknesses of laminae. Data on six hardwoods and nine home-grown softwoods have been obtained and a new method of testing comparatively thick laminae, employing a four-point loading technique, has been developed.

PLYWOOD BENDING

Standard bending tests have been completed on five different species of $\frac{3}{16}$ in. three-ply wood. Investigations have also been started on a large scale to determine the influence of various factors on the bending and setting to shape of Finnish birch plywood.

An improved experimental method of pressing and moulding plywood to varying degrees of double curvature has been devised, and has enabled data relating to maximum circumferential compression strains in the moulding of $\frac{3}{16}$ in. gaboon plywood to be obtained.

MISCELLANEOUS WORK IN SEASONING AND BENDING

At the request of industry, special tests have been undertaken to determine the minimum end-pressure necessary for the making of hairpin bends for "Windsor" chairs and the behaviour of items of furniture and surveyors' rods when subjected to moist and dry air conditions have been investigated.

Six visits have been made to firms engaged in seasoning and bending.

TIMBER MECHANICS

LAMINATED CONSTRUCTION IN HOME-GROWN SOFTWOODS

A promising field of study arising from the joint research with the Forestry Commission of the quality and properties of home-grown softwoods is concerned with their utilisation in laminated construction.

In this form of construction the process of gluing does not change the strength properties of the individual laminae. Consequently laminated and sawn timber members of the same cross-section are equally strong when they are both of clear material and have the same moisture content throughout. It is only when knots are present that laminating offers the possibility of design stresses higher than those applicable to sawn timbers. So that full advantage can be taken of this in practice, an extensive investigation has been undertaken in order to obtain quantitative data on the influence and incidence of knots in home-grown softwood species.

The investigation was concerned mainly with Scots pine, larch and Sitka spruce but included imported Douglas fir for comparative purposes. Material for the Sitka spruce studies was mostly from 30- to 40-year-old trees in which knot incidence is relatively high. In this class of timber the advantages of laminating can have an important bearing on its value for structural use.

The first stage in the investigation was the determination of the relationships between the size of knots present and the various strength properties. These were derived from the results of Laboratory tests made under controlled conditions on some 800 laminated beams and columns. The individual results of the bending tests on beams from one species, Sitka spruce, are shown in Fig. 1. These are plotted against the knot moment ratio (I_k/I_g), a ratio of the second moment of area of the major knots within a definite distance of the fracture, to the second moment of area of the full cross-section of the beams. The distance over which knots could be considered effective had to be determined and this was found to be within plus or minus 6 in. from the centre line of the fracture.

It can be seen from Fig. 1 that bending strength decreases with increase in knot ratio. The vertical scatter of the points is typical of the properties of a naturally variable material such as wood. A comparison of the coefficients of variation indicates that the scatter does not become significantly greater as the knot ratio increases; most of it arises from differences in density between the specimens. The straight line drawn through the points gives the regression of strength on knot ratio, allowance having been made for the density differences. The equation for this line may be expressed in such a way as to give values for

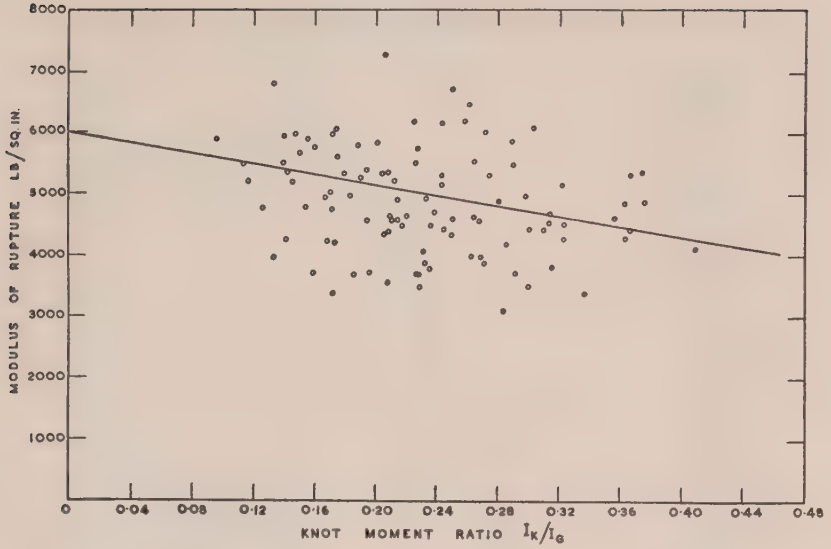


Fig. 1. The bending strength of laminated beams made from home-grown Sitka spruce plotted against the knot moment ratio.

a modification factor K by which the basic stresses for clear material can be multiplied to obtain the stress values appropriate to material with knots. For Sitka spruce the equation is $K=(1 - 0{\cdot}7x)$ where x is the knot ratio. Equations for other properties and species are also being derived.

Having established the influence of the knots on strength it becomes necessary to formulate grading rules and then to study the incidence of knots in laminated members fabricated from timber conforming to these rules. Such rules must be easy to apply and experience has shown that three grades having 50 per cent, 75 per cent and 100 per cent of the strength of clear material give the required simplicity and at the same time ensure that most of a random sample of material will fall within these three grades in reasonable proportions. Fig. 2 gives a cumulative frequency diagram for the major knots in "run of the mill' samples of Sitka spruce drawn from three regions in the United Kingdom. Some 80 per cent of these samples are within the grade requirements which limit the size of knots to $\frac{1}{2}$, $\frac{1}{4}$ and "zero" times the cross-section area. The grading rules also have to include corresponding limitations on the slope of grain although these become less important when knots are prevalent.

Any knots which occur within a lamination are restricted to that lamination only. The possibility that the largest knot for a grade will coincide in all laminations at one cross-section in a member must be remote. It is from this dispersion of knots that the advantage of being able to utilise higher stresses for design in laminated members arises. In the case of laminated beams the dispersion may be studied by determining the distribution of the knot ratios (I_k/I_g) for laminations selected at random.

Cumulative frequency diagrams are shown in Fig. 3 for beams with 4, 6, 8, 10, 14 and 20 laminations of the 75 per cent grade Sitka spruce. These were obtained by coding the actual knots measured in each foot length of the samples

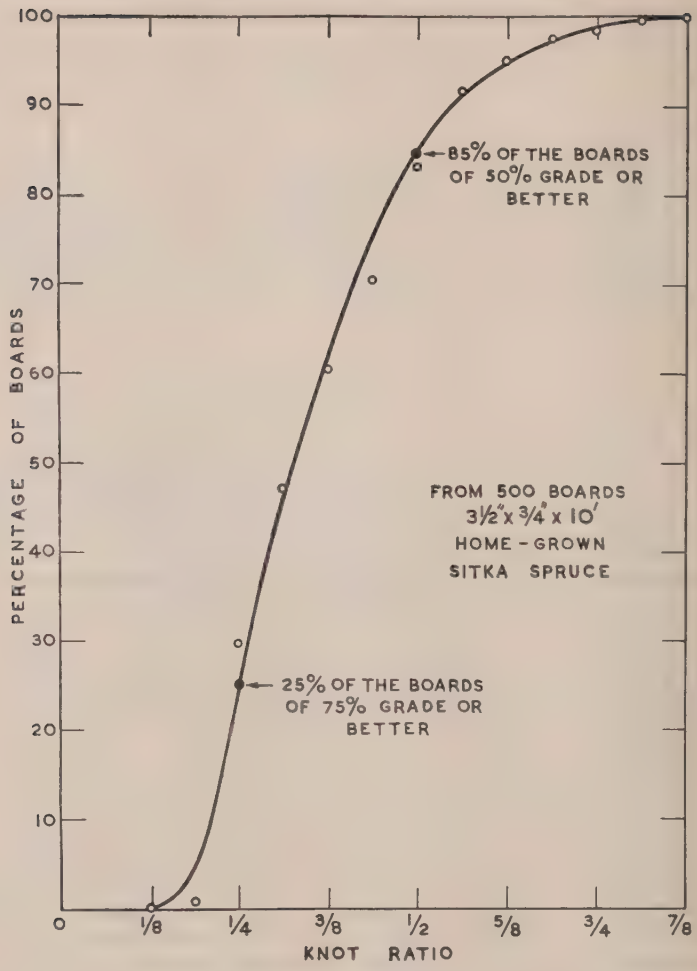


Fig. 2. The cumulative frequency diagram for knots in a commercial sample of home-grown Sitka spruce.

and calculating 500 random sections for each construction. The code was designed so that tapered knots, characteristic of the material, could be adequately dealt with and the calculations were made with the aid of a digital computer. It can be seen from Fig. 3 that the knot ratio decreases as the number of laminations increases.

If a probability of occurrence of once in one hundred is considered to be an acceptable risk then the limiting knot ratio for the 75 per cent grade Sitka spruce is as shown in Fig. 3. It is worth noting that this level of probability actually means that with no interaction between density and knot size the factor of safety will have the minimum value of 2·25 for only one foot length in about 5000 feet. For these limiting ratios the modification factor K can be calculated which will then enable the working stresses to be determined for any construc-

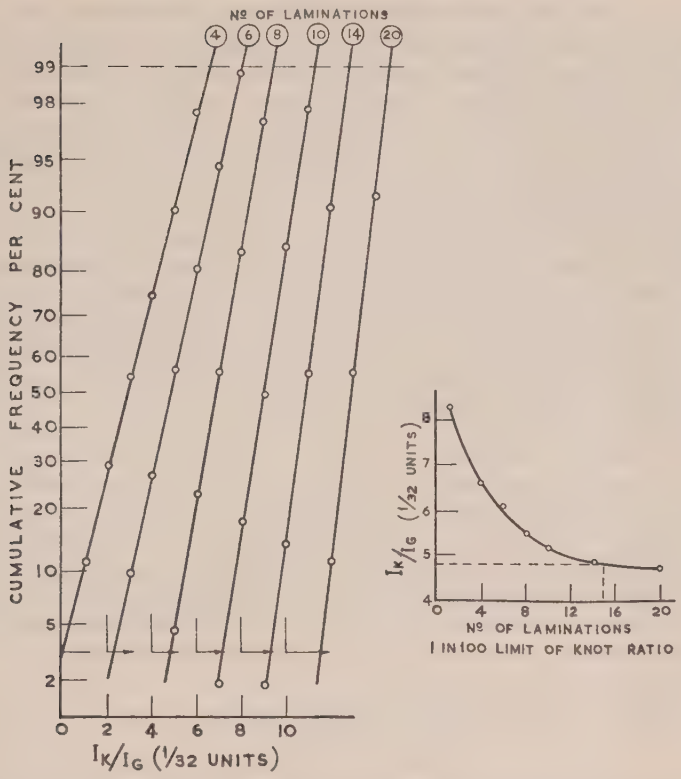

Nº OF LAMINATIONS
4 6 8 10 14 20
CUMULATIVE FREQUENCY PER CENT
99 98 95 90 80 70 60 50 40 30 20 10 5 2
0 2 4 6 8 10
IK/IG (1/32 UNITS)
IK/IG (1/32 UNITS)
8 7 6 5 4
0 4 8 12 16 20
Nº OF LAMINATIONS
1 IN 100 LIMIT OF KNOT RATIO

Fig. 3. The effect of number of laminations on the incidence of knots in beams made from home-grown Sitka spruce.

tion using this grade. Thus for a member with 15 laminations the limiting knot ratio is 4·8 in $\frac{1}{32}$ units, and the modification factor 0·9. The basic stress for clear Sitka spruce used under damp or uncovered conditions is 1100 lb/sq. in. and the appropriate working stress in bending is therefore 990 lb/sq. in.

Laminated timber arches made from home-grown Sitka spruce are illustrated in Plate 4. These are of tapered section and have a clear span at ground level of 30 ft 6 in. They rise to a height of 20 feet at the apex where a tractor and plough with a combined weight of 5 tons are freely suspended. The construction meets the specification given in the example above and under this load the bending stress is 990 lb/sq. in. over the greater portion of the length of the arches. These arches, which were exhibited at the Forest Research Station, Alice Holt Lodge, were designed and fabricated at the Laboratory on the basis of the knowledge gained from this investigation. The practical advantage gained by applying these results is reflected in an increase in working stress of some 20 per cent.

Similar analyses are being made for the larch, Scots pine and Douglas fir with the object of deriving either the separate modification factors or one common to all four species for the properties Modulus of Elasticity and Ultimate Strength in Bending and Compression.

QUALITY AND PROPERTIES OF HOME-GROWN SOFTWOODS

Investigation of the variability in quality and properties of the sawn home-grown Sitka spruce has given interesting results. Analyses made so far of four regions in England and Wales show that there is no significant difference in specific gravity between timber from these regions. There are, however, significant differences between the various sites within the regions and between the trees within the sites. There is no evidence of any real relationship between specific gravity and site quality class as rated by foresters.

All these investigations are proving of practical value when considering the utilization of home-grown softwoods for structural and other purposes. For example the Forestry Commission have been advised concerning the construction of an experimental bungalow and a two-storey office building from "run of the mill" home-grown softwoods. Advice has also been given to the Federated Home Timber Associations regarding the drafting of a suitable specification covering the use of home-grown timbers in pallet manufacture.

WORKING STRESSES FOR STRUCTURAL SOFTWOODS

The sampling of the structural softwoods, Canadian western hemlock, redwood and whitewood referred to in the Annual Report for 1958 (p. 12) has been completed. The detailed report on one of these species, western hemlock, has been published[6]. This emphasizes that although working stresses for pure western hemlock do not require much modification they should not be used for those consignments of commercial western hemlock which contain a proportion of western balsam, a much weaker species of softwood.

WOODWORKING

THEORY OF CUTTING

Although a great deal of empirical information, on which the woodworking industry depends, is available on the wood cutting process, and some preliminary theoretical work has been done in Russia[7], a satisfactory basis in the form of a Theory of Cutting applicable to wood has never been developed. For some years the Woodworking Section has undertaken experimental work aimed at the establishment of such a theory, and a study of the forces involved in simple rectilinear cutting has seemed most promising in contributing towards its development.

Previous Annual Reports have referred to the development of two machines for measuring the forces acting during rectilinear cutting. One operates at very low speeds, around 10 ft/min, taking measurements of high precision, while the other, the so-called "Whirling Arm" machine, has a speed range from 750 to 9000 ft/min, reaching well up into the range of speeds used in commercial woodworking practice.

The tests on the low-speed machine have now covered a range of depths of cut from 100 microns (0·004 in.) down to 4 microns. These have confirmed the results obtained for greater depths of cut, given in the Annual Report for 1958 (p. 15). The upper limit of depth of cut is determined by the stability of the apparatus, but is high enough to extend well into the range of commercial chip-thicknesses, and to overlap the range obtainable on the "Whirling Arm" machine. The lower limit is not fixed, but below 4 microns the "cutting" process is not one of cutting as normally understood, and a true chip is not obtained.

Obviously at these very small thicknesses a very sharp cutting edge is necessary for chip-formation. Simple theoretical considerations show that, even if a perfect cutting edge, *i.e.* one in which the front and rear faces of the cutter meet in a geometrical straight line of negligible thickness, could be obtained in sharpening, the extreme tip would break off as soon as cutting was attempted. In fact, although the very refined sharpening technique developed by Endersby[8] is employed, the thickness of the edge achieved on a high-speed-steel cutter has been found by optical measurements to be 1 to 1·5 microns. So it is not surprising that true clip formation is not obtained at depths of cut less than 4 microns.

This method of sharpening entails the formation of a small front bevel on the cutter, of a width of about 2·5 mm. That is to say, the front face of the cutter retains its true cutting angle for that distance only, thereafter sloping back at an extra $\frac{1}{2}°$ or so. Immediately after it has been severed from the wood, the cut chip passes up the front face of the cutter for a short distance before bending away forwards in the well known chip curl which gives the typical, spiral, rolled-up chip. It was considered that the change of angle in the cutter face might influence the formation of this chip curl and this possibility has been investigated.

A series of photographs was taken by high-speed flash photography during the course of actual cuts. Plate 5 shows a typical example. The front bevel ends at point A, and it can clearly be seen that the chip curls away from the cutter before reaching this. The distance for which the chip is in contact with the cutter face is (at 100 microns depth of cut) 0·2 to 0·4 mm, depending on wood species and cutting angle. Thus the existence of the change of angle cannot in fact affect the cutting as carried out on the low-speed machine.

One of the timbers used in the low-speed tests was sycamore and this was also used for an extensive series of tests in the high-speed "Whirling Arm" machine in which the maximum speed was taken up to 9000 ft/min, earlier tests having been limited to 7500 ft/min.

These tests did not disclose any marked trend for cutting forces to vary with speed, indeed the variations observed were less than those previously reported[9]. But it was found that the results were not in agreement with those from the low-speed machine at similar angles and depths of cut.

A further series of tests was therefore made on both machines, using carefully matched wood samples and identical cutting angles and chip thicknesses. They confirmed the discrepancy, the results for the low-speed machine showing a cutting force f_c (parallel to the line of cut) twice as high at 10 ft/min as that at 1000 ft/min on the other machine.

The "Whirling Arm" machine was therefore modified to make possible a series of tests in the speed range not previously covered, i.e. 20–750 ft/min.

The results obtained at the intermediate speeds show that the cutting force rises steadily as speed is reduced down to about 100 ft/min, but that below this speed the variation of the force is more complex but in the same range as the forces observed on the low-speed machine. The results from the low-speed machine fall between those observed on the "Whirling Arm" machine at 20 ft/min and at "zero" ft/min, i.e. when the wood was pressed against the cutter.

A report on this work is now being prepared, but it will be evident that the two machines have made possible the demonstration of significant differences in cutting forces between the low speeds already investigated by various research workers, and the high speeds characteristic of commercial woodworking practice.

Assistance has been given in the editing of the English translation of a Russian book on the theory of woodcutting[7], and it is hoped that the experimental results obtained in this Laboratory may provide a check on the theories set forth in the book.

FOREST TOOLS

The increasing use of the one-man petrol-driven chain saw of various types of design by forest workers in many European countries has focussed the attention of the Food and Agriculture Organization's Joint Committee for Forest Working Techniques on efficiency tests for these chain saws which would receive international recognition. The Study Group on the Testing of Forest Machinery has accordingly drawn up a protocol[10] covering an extensive series of bench and field tests for the consideration of all interested authorities.

The Laboratory has undertaken the testing of these chain saws in accordance with the protocol. The Laboratory's part has been confined to bench tests which involve the testing of the saw as a complete machine when engaged in cutting.

An apparatus has been constructed in which the chain saw and the log to be cut can both be mounted so that the force with which the saw is fed into the cut can be controlled, and the pull of the chain on the timber can be measured. Chart-recorders are used to provide continuous readings of this pull, and of the speed of the chain during a cut; from the speed and pull the horse power actually expended in the sawing process (separated from that absorbed in the machinery and by friction of the chain in its guide) can be calculated.

Although a single cross-cut of a 12 in. diameter log may take only 7 seconds, a technique for measuring the rate of fuel consumption of the chain saw engine during this period has been developed. Thus a true specific fuel consumption for the saw when cutting can be obtained. Tests have been completed on several saws, and further tests will be undertaken as required.

ASSESSMENT OF MACHINE FINISH OF SOFTWOODS

The extent and severity of defects which may occur in the planing of a softwood determine the quality of its machine finish and its suitability for a particular purpose. A measure of machine finish has not been available hitherto and an investigation aimed at developing suitable techniques for assessing this woodworking property has been carried out.

Four types of surface defect may occur in the planing of softwood — tearing due to irregular or inclined grain, raised grain caused by the recovery of the spring wood after compression by the cutters, "woolliness" due to the dragging up and incomplete cutting of the surface, and chip bruising.

Although it is possible to assess the severity of these defects and to form an opinion regarding the quality of the finish from a casual inspection of the surface, such a method of working cannot be considered reliable. In the first place the eye is attracted to the more obvious defects and may ignore those which may be more troublesome in subsequent finishing treatments. Secondly there is the likelihood of variation in adopted standards of defect severity, especially where inspection is undertaken at intervals over a long period of time. And, thirdly, there is the difficulty that the appearance and therefore the apparent severity of a defect changes as the illumination of the surface is altered. The appearance of machining irregularities is most pronounced where the surface of the wood is viewed at right angles and is illuminated by a beam of light at a large angle of incidence. It also depends on the orientation of the beam with

respect to the direction of cutting; thus tearing appears to be most pronounced where the direction of the beam of light corresponds with that of the feed motion of the timber in machining.

For an investigation of the machine finishing properties of softwood, the following method has been devised to minimize the inspection difficulties mentioned above. A reduced area of 12 sq. in. was selected for inspection and a set of reference photographs showing each class of defect at three levels of severity prepared for comparison during inspection of test material. This test material consisted of 4 in. tongued and grooved flooring strip which was machined according to standard commercial practice. With such material the defect known as raised grain is best exhibited by lighting the specimen from the side at right angles to the length of the strip, whereas the appearance of defects such as tearing and "woolliness" is more pronounced where the lighting is along the length of the specimen. Because the appearance of raised grain is the more critical as regards the direction of illumination, it was decided for the sake of convenience to carry out the inspection for all defects with side lighting. The apparatus used is shown in Plate 6 and consists of a lens system providing a sensibly parallel beam of light about 3 in. in diameter and a lipped table to support and guide the specimen. The table is inclined to the light beam to provide an angle of incidence of 85°. To ensure constant illumination of the wood surface, inspections are carried out in a darkened room.

This method of measuring machine finish was developed in order to obtain a quantitative assessment of the severity of the defects occurring in the planing of home-grown softwoods and, so far, its application to tests on Sitka spruce has been promising.

COMPOSITE WOOD

STUDIES OF GLUES AND GLUING

(a) *Durability of adhesives*

High temperature effects. Concern has been expressed that the heating effect of the sun on wooden structures may be damaging to the glued joints within them, and to summarize information on the subject, a survey[11] of existing reports was made. Tests with aircraft wings had shown that temperatures of 65°C (150°F) could be developed on their surfaces in England but that their duration and frequency were small in terms of the year. The cumulative evidence with a variety of test-pieces made with cold-setting phenolic and resorcinol glues and exposed out of doors for ten years showed that degrade from insolation effects as such is negligible. The behaviour of the glues might be different if the periods of heating were more prolonged and at a higher temperature, and this matter is now being investigated with a wide range of adhesives.

Series V and C. Originally set up in 1954, Series V and C are long-term investigations into the durability of glues for plywood manufacture and assembly work. They are designed to be cumulative so that new glues can be included. In 1959 there have been added a further seven phenolic adhesives containing a large range of filler, i.e. a non-reactive component of the mixed glue. It is known that the initial quality of the bond falls as the filler content rises beyond a certain amount, and the relation between this and the durability of these phenolics under exposure to weather is being studied. The results to date have been published[12].

Bulletin 38. From 1955, a summary has been issued yearly containing the accumulating results with the long-term glue durability tests, and the data up to January 1959 have now been published[13]. Included in the Bulletin are results of sustained loading tests on glued joints of the type described in the Annual Report for 1957 (pp. 21–22). With resorcinol, urea, casein and animal glues, there have been no failures in three years under a loading 30 per cent of the ultimate breaking load.

Marine conditions. A further examination has been made of the glued test-pieces in the motor gun-boat maintained for the Laboratory by H.M.S. *Dolphin* at Gosport. A further two years will be required to finish the tests, but part of the material has completed its allotted ten years, and a detailed analysis has been made[14].

(b) *Gluing techniques*

Gluing oak with resorcinol resins. In the Annual Report for 1954 (p. 20), an account was given of preliminary work on the technique of gluing African mahogany and oak with cold-setting resorcinol resin adhesives. There were no difficulties with the former, but oak proved troublesome, and a wider investigation was begun. The test-pieces were 16 in. long and 5 in. wide made from thirteen parallel-grained laminations 0·31 in. thick, in the manufacture of which forty variables were examined. Matched sections of the blocks were stressed by a wetting and drying cycle imposed initially and also after a year's exposure to weather, the criterion being the amount of separation of the glue lines at the end-grain surfaces.

The results have now been published[15]. The outstanding feature of the experiment was the wide differences in performance between the four brands of glue with oak (two good, one moderate and one completely unreliable) whereas the same four were faultless with African mahogany. Post-treatment of the block by heat showed no generally beneficial effect, but rather surprisingly a marked improvement in bond quality took place during the year's exposure of the blocks to weather. The experiment has solved some problems but has posed many new ones and a further series is now in progress.

Factors in gluing. The 1958 Annual Report (p. 21) referred to a study of the function of pressure and associated factors in the gluing of wood. This work has continued and a number of additional variables has been examined[16]. If instead of a single glue spread each surface is coated with half the same amount of adhesive, then the bond quality of the resultant joint is increased by 1 in the scale 0–10. The effect is independent of the bonding temperature within the range 25°C (77°F) to 95°C (203°F) and is undoubtedly due to the mechanical wetting of the two surfaces by the spreading action. The surface condition of the wood is also important and a difference has been recognized between the two sides of a planed piece. Sanding before gluing tends to minimize rather than to eliminate such effects. No relationship has been found between the bond qualtiy and the original position of the wooden test-piece in a 4 ft log of 3 ft diameter.

(c) *Testing of glued joints*

Statistical aspects. Statistical analyses[17] have been made of results of tests on adhesives to current British Standard Specifications, using data obtained at the Laboratory. With the mechanical tests, failing loads for the several types of test-piece and types of glue have been examined for average values and for spread of results within and between sets and Table 1 gives the values in abridged form.

Table 1

Statistical analysis of glued joints to British Standard Specifications

(All figures in pounds to nearest 5)

British Standard Specification No.	Type of glue	Dry test			Cold wet test		
		AV. F.L.	S.D.	Diff.	AV. F.L.	S.D.	Diff.
		(1)	(2)	(3)	(1)	(2)	(3)
1203 on hot setting plywood glues	UF	335	30	35	350	40	45
	PF	325	40	50	325	35	45
1204 on gap filling assembly glues	UF	585	65	80	515	60	75
	PF	535	60	75	470	55	70
	RF	585	70	90	495	55	70
1204 on close contact assembly glues	UF	770	75	100	600	70	90
	PF	780	85	110	650	80	105
	RF	780	75	100	635	65	85
1444 on close contact assembly glues	Casein	720	75	95	165	35	45

(1) Failing load for sets of six test pieces.
(2) Standard deviation of individuals about own mean.
(3) Difference between means of two sets for statistical significance at the 95 per cent level, assuming the standard deviations to be equal.

It is of interest that the coefficient of variation is nearly the same for all tests (except casein in the wet state) and is about 11 per cent. The histogram and frequency distribution curves for two groups of data are shown in Fig. 4(a),(b).

A knife test for plywood which was developed by the Laboratory in its present form (see the Annual Report for 1955, p. 27) and subsequently adopted for two British Standards[18, 19] has been examined for variations in respect of one tester operating alone and several together, the plywood itself, and influence of the number of boards sampled. The bond quality within a board varies not only between glue-lines but from place to place in any one, but when sufficient data were examined for the relation between mean values and the spread of individuals a good agreement was found between observed values and those calculated by the binomial distribution. Actual and theoretical curves for bond qualities of 4·1 and 7·9 are given in Fig. 5.

Assessment of bond quality. Considerable thought has been given to the meaning of bond quality in its wider sense, and whether or under what conditions appearance of the severed surfaces gives a better guide than the failing load obtained by a mechanical test. A paper[20] on the subject has been published. The knife test, which is of course one based on appearance, has — at least in this country — become the accepted standard in judging plywood, and an analogous method is under development for assembly joints of the kind met with in laminated beams.

Testing machine for glued joints. The radio frequency glue-setting investigations described on page 24 include the manufacture and testing of B.S. 1204: 1956 type of close-contact joints made under controlled radio frequency heating. It is essential that the pulling be done quickly and immediately after manu-

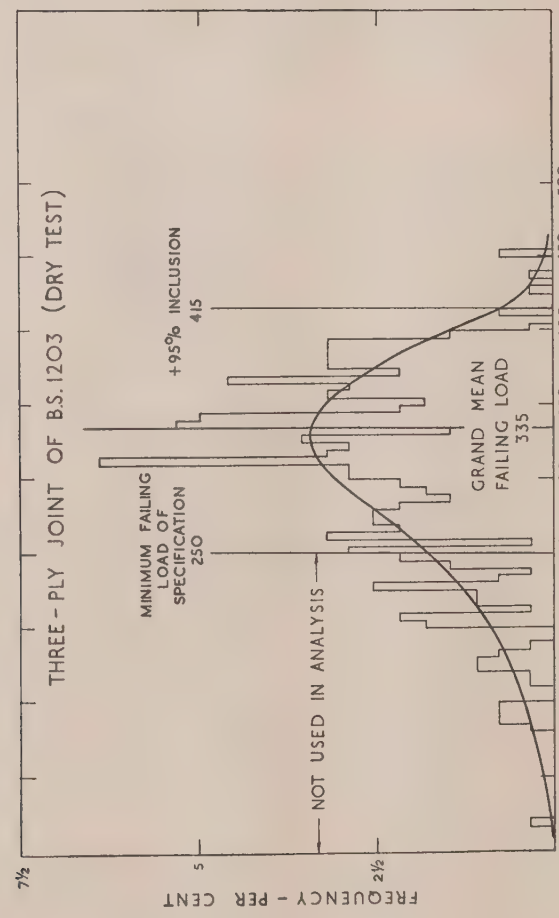


Fig. 4(a). Statistical analysis of British Standard glued joints. Frequency distribution curve and histogram for the three-ply joint.

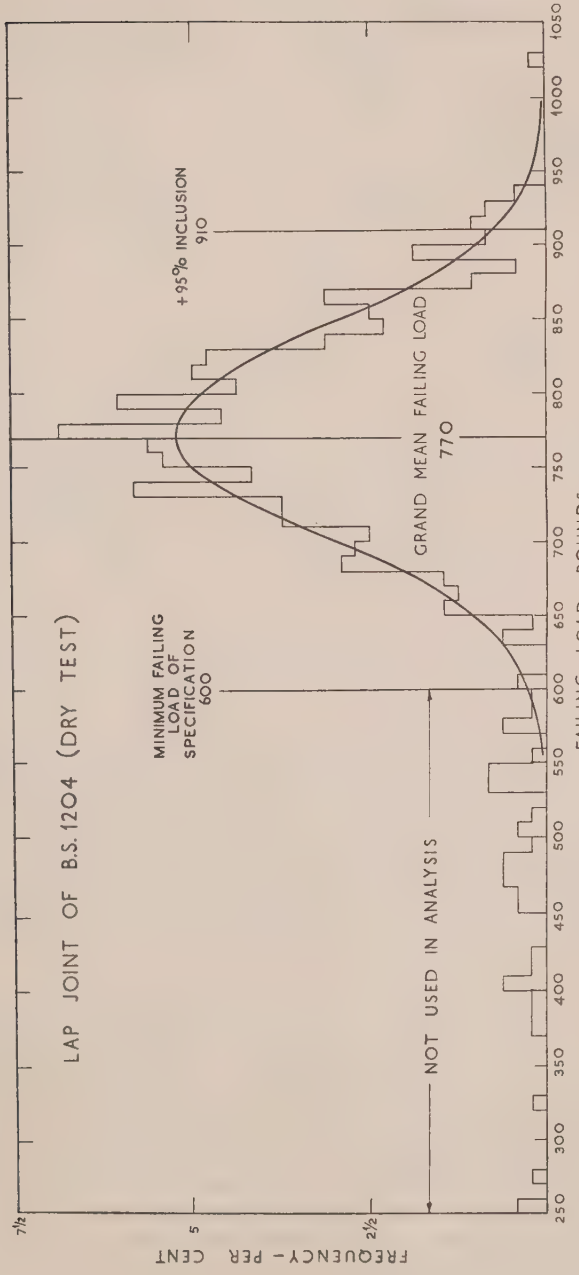

LAP JOINT OF B.S. 1204 (DRY TEST)
MINIMUM FAILING LOAD OF SPECIFICATION 600
+95% INCLUSION 910
GRAND MEAN FAILING LOAD 770
NOT USED IN ANALYSIS
FREQUENCY - PER CENT
7½
5
2½
250 300 350 400 450 500 550 600 650 700 750 800 850 900 950 1000 1050
FAILING LOAD - POUNDS

Fig. 4(b). Statistical analysis of British Standard glued joints. Frequency distribution curve and histogram for the close-contact lap joint.

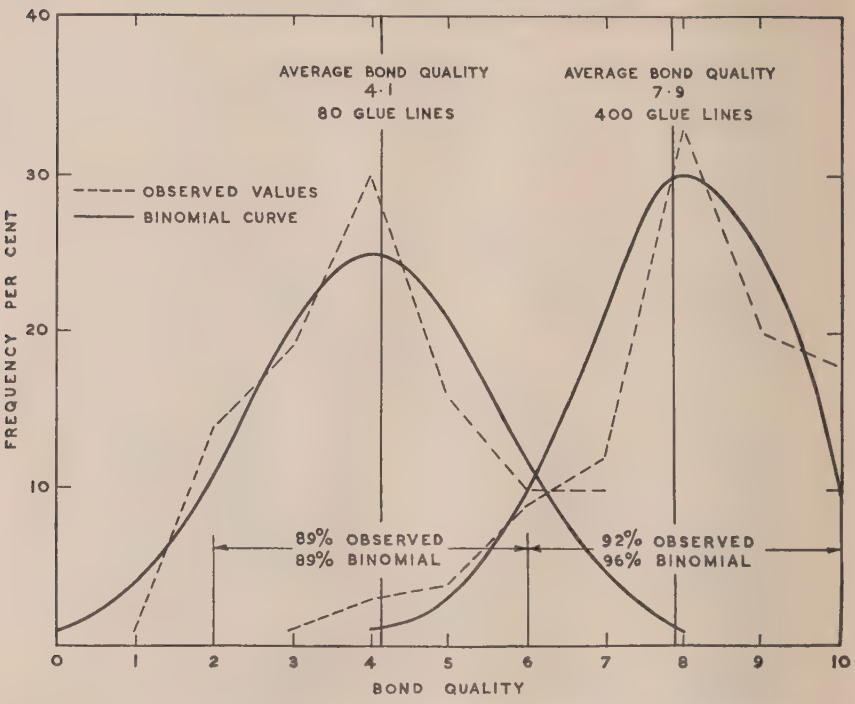


Fig. 5. The knife testing of plywood. Observed and calculated frequency distribution curves for two mean bond quality levels.

facture so that the residual heat in the joint does not continue the glue cure and prevent a comparison of the electrical conditions alone. With the standard test machine of B.S. 1204 : 1956 the load is applied at between 300 and 600 lb/min and one dozen joints take over 30 minutes to test. This was considered too slow and a new machine has been constructed, the main features of which are the ease with which the joint can be inserted and clamped in the machine and the short time needed for the actual test. The new machine enables a dozen joints to be tested in $3\frac{1}{2}$ minutes, i.e. in approximately one tenth that needed in the standard.

PREPARATION OF VENEER FOR PLYWOOD MANUFACTURE

Tension wood in veneer logs. It is well known that the presence of tension wood results in a rough, woolly surface in sawing and machining operations on solid wood. This "woolliness" is equally troublesome in veneers and plywood where the finish of much larger areas may be marred; in the plywood, sanding produces in the tension wood areas a surface similar to that of suede leather. How far the condition of the surface is influenced by various factors during cutting, such as lathe settings and pre-treatment of the billets, was the subject of an investigation on *Khaya ivorensis* selected for its high content of tension wood.

It was found that with standard lathe settings, tension wood veneer free from "woolliness" was obtainable only after pre-treatment of billets at a temperature of 5°C though the normal wood peeled at this condition was rather rough. Increases in pre-treatment temperatures gave rise to increasing woolliness of

tension wood and decreasing roughness of normal wood. The best compromise was effected by pre-treating at a temperature not greater than 45°C instead of the normal 65°C, and by reducing the nosebar gap from between 0·045 and 0·050 in. to between 0·040 and 0·045 in.

Of the other variables tested, none was so marked in effect as pre-treatment. The use of a range of knife grinding angles between 20° and 30° showed that there was a slight tendency for an increase in grinding angle to produce an increase in roughness of normal wood and a decrease in the woolliness of tension wood. Cutting speeds of 50, 150 and 300 ft/min caused no noticeable difference in the woolliness of tension wood nor in the roughness of normal wood.

On sanded plywood, tension wood always gave rise to "suede" even though the veneer had apparently peeled smoothly.

Bark form and veneer figure in birch. It has been found that the wood from certain birch trees has a decorative appearance that is commonly known as flamy figure. It is considered that this figure may be associated with a particular type of bark and if this can be established it should be possible to select, for breeding purposes, trees that will contain the desired figure.

Exploratory tests were carried out in 1957 in collaboration with the Forestry Commission and gave promising results. The work[21] has been extended to include an investigation of the relationship between the appearance of bark and grain generally.

Veneer 0·032 in. thick was obtained by peeling and slicing a sample of twelve trees all about 60 years old, having rough and smooth bark (see Plate 7), and the figure found within each tree was compared with photographs of the bark covering the full circumference.

It was shown that in general rough bark was associated with some form of distorted grain. Four types of figure (see Plate 8) were recognizable and by comparing circumferential lengths of veneer taken from near the outside of the tree where figure was more prevalent with others from different radial positions in the tree it was possible to trace the origin of some of the figure. Catspaw and wrinkle figure, which were present near the outside of the tree, were found to originate in small knots, sometimes occurring within a few inches of the pith. However, no such origin could be found for flamy figure which was also traceable to within about an inch of the pith; this lack of visible evidence of a direct cause for the development of flamy figure strengthens the supposition that it may be an inherited character. The figure results from wavy grain; irregular waves occur in both the radial and tangential directions. On a cleft radial surface the crests of the waves are inclined at an angle to the axis of the tree in a downward direction from the pith to the bark while on a tangential surface the crests are more nearly at right angles to the axis.

No precise connection could be established between the presence of flamy figure and any particular type of rough bark though there were indications that it had some association with rough bark having wide, deep, fairly continuous fissures. The presence of the figure at very small diameters, when presumably the bark would have been smooth, suggests that a relationship with the bark develops with age and it may be that a distinctive bark feature is only apparent in trees much older than those tested.

It was deduced that there may be some connection between the development of the butt and the occurrence of flamy figure, for in those trees where it was most pronounced the figure was usually found only in the six foot butt length

of the tree; in addition, in several instances some flamy figure was found on the edges of buttresses of smooth barked trees.

Trials of timbers for plywood manufacture. Small-scale trials of Commonwealth species for plywood manufacture have been made on nkoba, mushebeya, African satinwood and *Shorea waltoni.*

PROPERTIES OF COMPOSITE WOOD PRODUCTS

Surface checking of plywood. The Annual Report for 1953 (pp. 24–26) described routine tests to assess for various species the tendency to check in the form of plywood when exposed to weather for a period of two years. Results with fifty-nine species were then available, and a further twenty-six have since been added[92].

Surface protection of plywood. As a logical extension to the foregoing, means of imparting a weatherproof surface to plywood are being examined, viz. the creating of a tough reinforced plastic face as an integral part of the plywood. (See also the Annual Report for 1957, p. 23.) In collaboration with suppliers, faced panels have been prepared and, amongst other tests, have been exposed to weather and the alternating conditions of the Laboratory's Tropical House. Most of the materials were papers impregnated with phenolic type resins, and after a year and a half's exposure it is apparent that although all the panels have lost their initial gloss, the facings have inhibited checking of the wood even under exposure to sun and rain on a site adjacent to a railway track. On the underside of these same panels, and in the Tropical House treatment, no deterioration has occurred. A melamine treated film has, however, failed completely under weathering although it is satisfactory in the Tropical House cycles.

RADIO FREQUENCY HEATING

Radio Frequency Panel. The Radio Frequency Panel was first convened in 1947 with the object of providing a liaison between the Laboratory and those organisations interested in the use of this form of heating in the wood industry. The Panel met twice yearly until 1951 when it was suspended because staff shortages interrupted experimental work. The need for research was always recognised, however, and in 1954 work was restarted on the application of radio frequency heating to glue setting. The Panel has now been re-convened and two meetings have been held to discuss the Laboratory's research programme and to exchange information. One topic discussed was the application of radio frequency heating to the curing of the adhesive in large assemblies, such as laminated beams and a survey has been made of the available information.

Influence of frequency on glue setting rates. A major investigation has been planned to study the function of the generator frequency and other associated factors in the gluing of wood under radio frequency heating. The following variables are being examined:

(a) The frequency of the generator (5 to 25 Mc/s)
(b) The type of heating (glue line or transverse)
(c) The type of glue (synthetic resins of the urea-, phenol-, and resorcinol-formaldehyde types)
(d) The moisture content of the wood (7 to 18 per cent)
(e) The heating time necessary for a glue cure (10 to 90 seconds)

The experimental procedure is to make B.S. 1204 : 1956 type of close-contact joints under each combination of variables and to find, by means of a

strength test, the voltage gradient necessary for the optimum glue cure. Essential to the work was a valve voltmeter which was designed and constructed[23] in collaboration with the National Physical Laboratory to measure the balanced voltage between the electrodes of the gluing jig. Capacitive dividers from each electrode to earth supply a reduced voltage which is rectified by germanium diodes and taken to a moving coil meter. The initial calibration tests, however, revealed a source of error in the indication due to radiation from the tuning capacitors and inductors and from the jig itself. Additional screening of the instrument was only partly successful and the complete radio frequency circuit external to the generator has now been surrounded by a double-screened, copper mesh enclosure. This arrangement has proved successful and the experimental work is now well in hand.

LIAISON AND COLLABORATION

The Composite Wood Research Panel, created in 1958 by combining the former Adhesive Makers' and Plywood Research Panels, continues to provide a means of liaison with industry and other research organisations, whilst the Composite Wood Corresponding Committee fulfils the same function between the Forest Products Laboratories in the Commonwealth and in the United States.

WOOD PRESERVATION

INVESTIGATIONS ON SITKA SPRUCE

These are part of the general study of the properties of Sitka spruce and their variation with site and quality classes. Three properties are being measured in this section, namely durability, resistance to impregnation, and permeability. Durability is being assessed by an accelerated "graveyard" test using samples of 1 in. by 1 in. section. Resistance to impregnation is being measured in the normal way by treating samples by a standardized pressure process and recording the absorption and penetration of liquid obtained. Permeability is being obtained from observations on the rate of flow of nitrogen through the wood. Only the longitudinal permeability is recorded but separate values for heartwood and sapwood are obtained. Both resistance to impregnation and permeability are being measured as, although they are related, it is not usually possible to derive one satisfactorily from the other and it is an advantage to have a knowledge of both.

THE LOSS AND MOVEMENT OF CREOSOTE IN WOOD DURING SERVICE

An investigation is being carried out into certain aspects of the mode of action of creosote as a wood preservative. The initial part of this work is concerned with the loss and movement of creosote in treated wood during service. Little is known about this subject mainly because of the difficulty of obtaining suitable material of any appreciable age whose initial retention and distribution of creosote are known from which these changes could be assessed. The present work is being carried out on material treated at the Laboratory about 25–30 years ago and whose treatment and history are known. So far two round posts of *Pinus sylvestris*, one creosoted by the full-cell and one by the empty-cell process, which have been in service for 30 years have been examined. In both posts it was found that the loss of creosote from the above-ground part was much greater than that from the part below the ground. The results indicated

that this difference could not be explained solely by a difference in the loss by evaporation from the above- and below-ground sections of the posts but must be due partly to a downward flow of creosote towards the butt during service. A diagram of the distribution of the residual creosote is shown in Fig. 6. Nor-

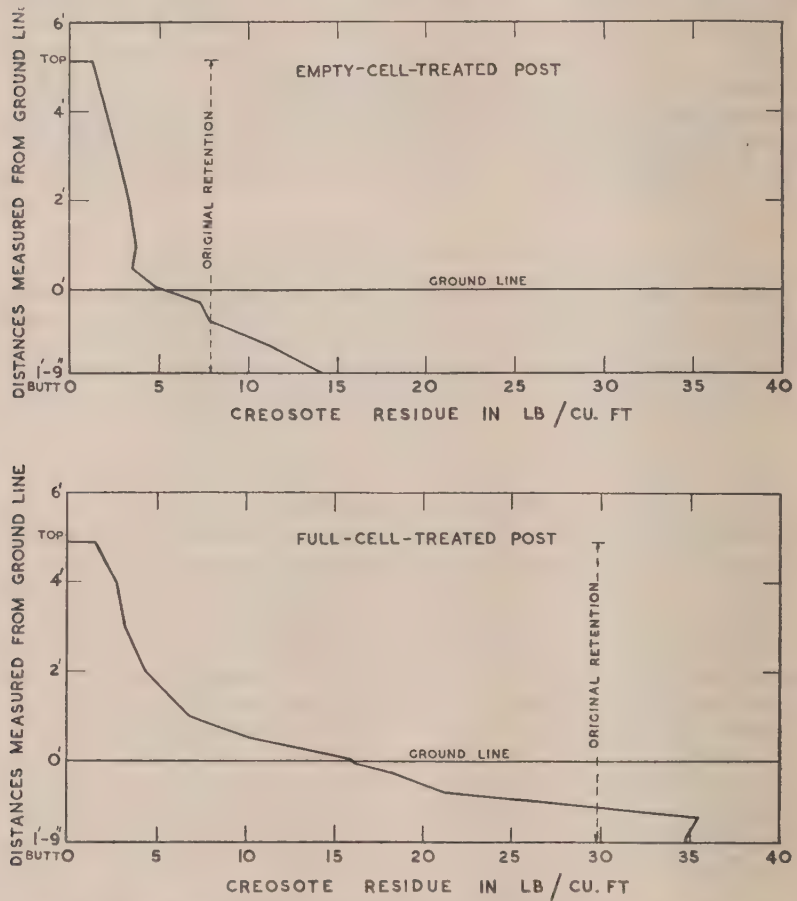


Fig. 6. Distribution of residual creosote in redwood posts after thirty years.

mally the vulnerable part of timber set in the ground is a zone extending from about ground line to about a foot below, and the life of the structure will depend on the preservative action in this zone. It is evident from the results mentioned above that this will depend not only on the generally recognized factors such as the initial loading, fungicidal value and permanence of the creosote, but most likely also on factors governing its movement in the timber such as its viscosity, the permeability of the wood and possibly the relative lengths of the above- and below-ground part of the pole or post. A report on this work has been published[24].

One of the difficulties in any investigation of this kind is that there is no generally accepted method for the quantitative estimation of aged creosote in timber. It has lately been shown[25] that extraction with a single solvent such as

toluene, which is the standard procedure for freshly treated wood, does not give complete recovery of creosote residues in timber that has been in service for a long time. This is especially so where the timber has been exposed to the weather, and it is necessary to make separate extractions with two different types of solvent to obtain a satisfactory recovery. Some work has been carried out at the Laboratory on the estimation of aged creosote residues and with some 48 years old material the above finding has been confirmed. On the other hand practically the whole of the creosote residue was recovered by a single solvent from the 30 year old posts examined in the present investigation. This suggests that the changes in creosote which occur during service, causing it to become partially insoluble in certain solvents, may occur to considerably different extents, possibly because of variations in the composition of the original creosote or different periods of service.

A source of error in the determination of creosote in wood by solvent extraction is that natural wood extractives are removed at the same time. Owing to the complex composition of the two extracts no method of separating them has been developed and a large error can result when the amount of creosote residue in the wood is small. One method of estimating the amount of natural wood extractives in the mixture which avoids difficulties arising from its complex composition appeared to be to measure the radioactive carbon 14 content of the mixture. This would be proportional to the amount of natural wood extractive in the mixture since this carbon isotope would not be present in the creosote. Unfortunately, however, the procedure for measuring the very low level of radioactivity from the natural carbon 14 content of materials is at present too elaborate for estimations of the above type.

NATURAL DURABILITY OF WOOD

A field service trial to assess the natural durability of different species of wood has been in progress since 1932. Interim results on about a hundred species were published in 1949 in *Forest Products Research Record* No. 30. Further results on these and on about thirty more species which have been put under test since then have been given in a revision of the report[1-6] made this year. Although the tests on many of these species are not yet complete an estimate of the final average life of the specimens has been made so that a durability rating of all the species could be given.

Data obtained from this investigation and from a subsidiary one on the effect of cross-sectional dimensions on the life of timber in the ground have recently been very useful in estimating the life of home-grown oak for fencing. Information on the life of English oak and other home-grown species, with and without preservative treatment, was required by a committee set up by the Forestry Commission to advise the Ministry of Transport on the suitability of home-grown timbers for the fencing of the new motorways. In view of its traditional use for the purpose it is surprisingly difficult to obtain reliable data on the useful life of oak fencing.

EFFECT OF IMMERSION IN WATER ON THE PERMEABILITY OF WOOD

Previous work described in the 1958 Annual Report (pp. 26–29) showed that water storage markedly increased the permeability of the sapwood of Scots pine and thereby eliminated its tendency to bleed after treatment with creosote. It indicated also that there might be a similar effect on the permeability of other home-grown softwoods, such as Sitka spruce, which are very much less permeable

than the sapwood of Scots pine and difficult to impregnate well with preservatives. This has now been confirmed. Matched samples of Sitka spruce and of Douglas fir and Japanese larch have been seasoned after various periods of water storage and then impregnated by a standard pressure process. The amounts of preservative absorbed in lb/cu. ft compared with that absorbed by samples seasoned directly after cutting are given in Table 2.

Table 2

Amounts of preservative absorbed in lb/cu. ft

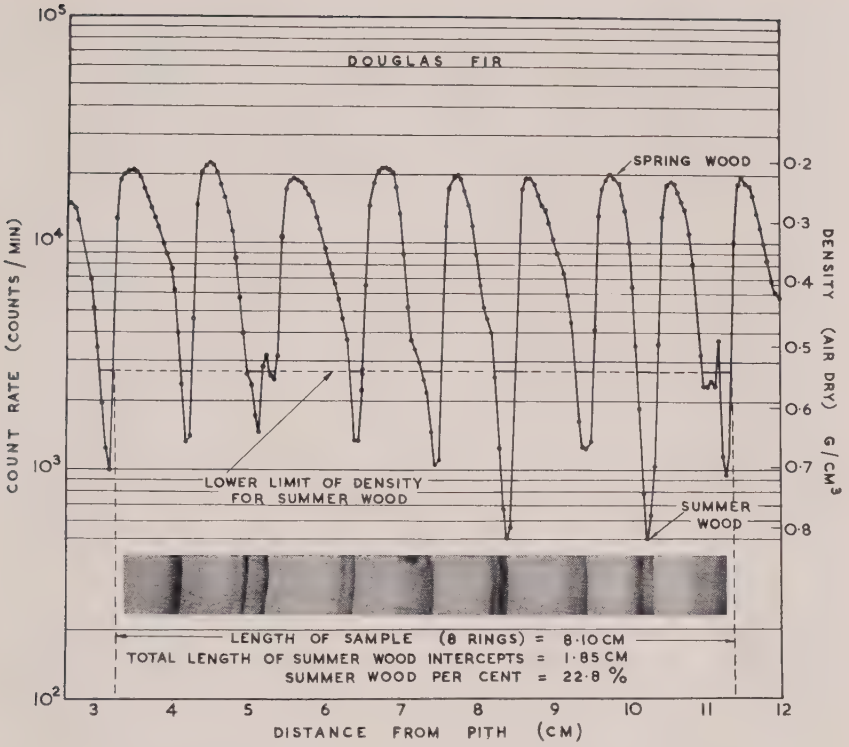
	Not water stored	Stored in water for		
		3 months	6 months	20 months
Sitka spruce	9	23	31	34
Douglas fir	2	—	13	17
Japanese larch	4	—	17	17

In general the penetration of preservative in the water stored material was deeper and more uniform than in the unsoaked samples (see Plate 9). In all three species the improvement in penetration is particularly noticeable in the spring wood.

TREATMENT BY IMMERSION

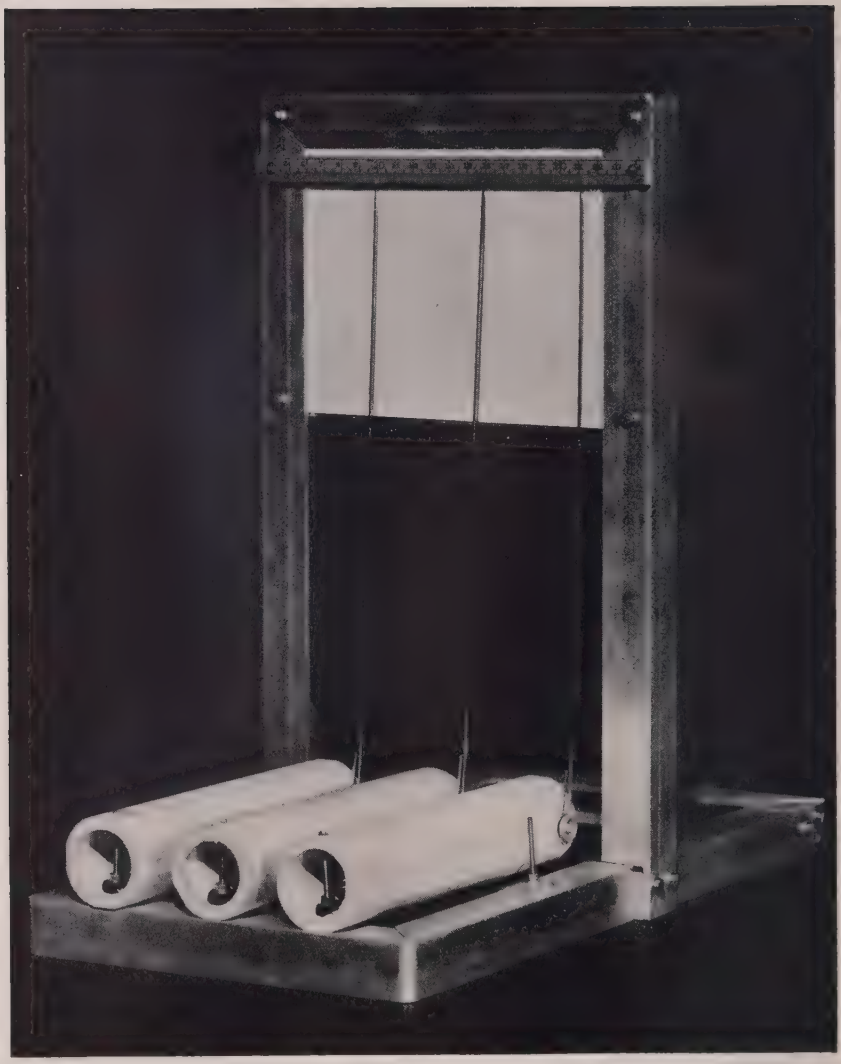
The initial part of this investigation was concerned with the degree of treatment that can be obtained in practice with the sapwood of redwood which is commonly treated by this method, and the results have been given in the Annual Report for 1957 (p. 26). Further work has been carried out to investigate the mechanism of penetration of preservatives into the sapwood of this species during immersion and the factors which control it. It has been found that there are three stages in the treatment. First there is a very rapid absorption of preservative into the open-ended tracheids at the surface which is completed in about 10 seconds or so. From then on absorption and penetration occur at a very much slower rate and are approximately proportional to the square root of the time of immersion. The last stage occurs after the timber is removed from the tank when the preservative already absorbed may continue to penetrate further into the wood and reach a considerably greater depth than that attained immediately after treatment. This secondary penetration takes place mainly along the rays and the extent to which it occurs depends on the physical properties of the preservative. This mode of penetration is basically the same for all the main types of preservative.

There is not very much difference in the amounts of the different preservatives absorbed by Scots pine sapwood during immersion but there are considerable differences between the depths to which they penetrate. Certain of the organic solvent type are the most penetrating and the water solution type are the least; one has about six times the penetrating power of the other. Conversely the concentration of the organic solvent type in the penetrated part of the wood is only about one sixth as great as that of the water solution type. These differences in penetration and concentration between the various types of preservatives are probably a main cause of the anomalies which occur from time to time in the testing of preservatives applied by superficial methods.


DOUGLAS FIR
SPRING WOOD
SUMMER WOOD
LOWER LIMIT OF DENSITY FOR SUMMER WOOD
LENGTH OF SAMPLE (8 RINGS) = 8·10 CM
TOTAL LENGTH OF SUMMER WOOD INTERCEPTS = 1·85 CM
SUMMER WOOD PER CENT = 22·8 %
COUNT RATE (COUNTS / MIN)
DENSITY (AIR DRY) G/CM³
DISTANCE FROM PITH (CM)

Determination of percentage summer wood by the β-ray method

PLATE 1



Apparatus for measuring twist

PLATE 2

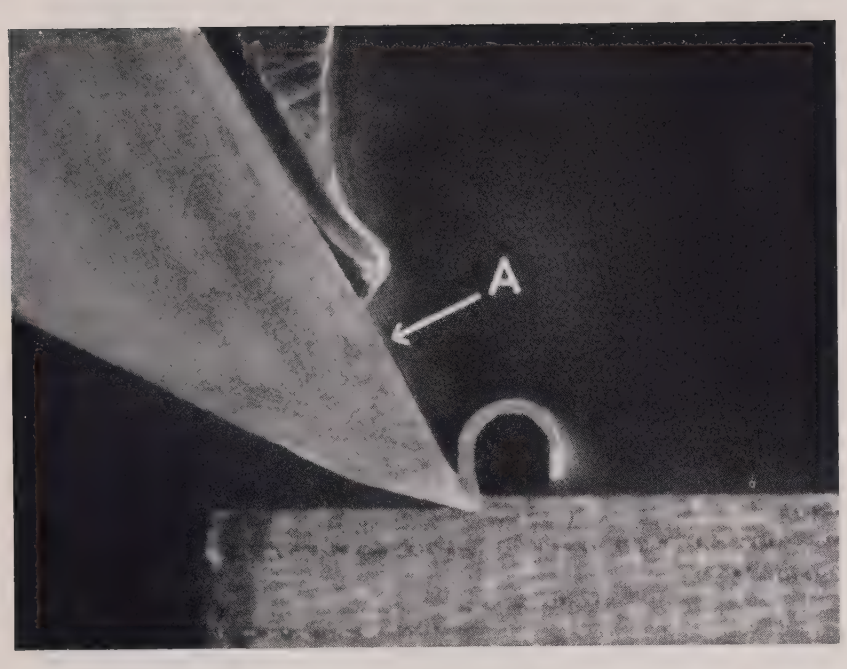
Kiln load of Sitka spruce clamped to a twisted foundation

PLATE 3

By courtesy of the Forestry Commission

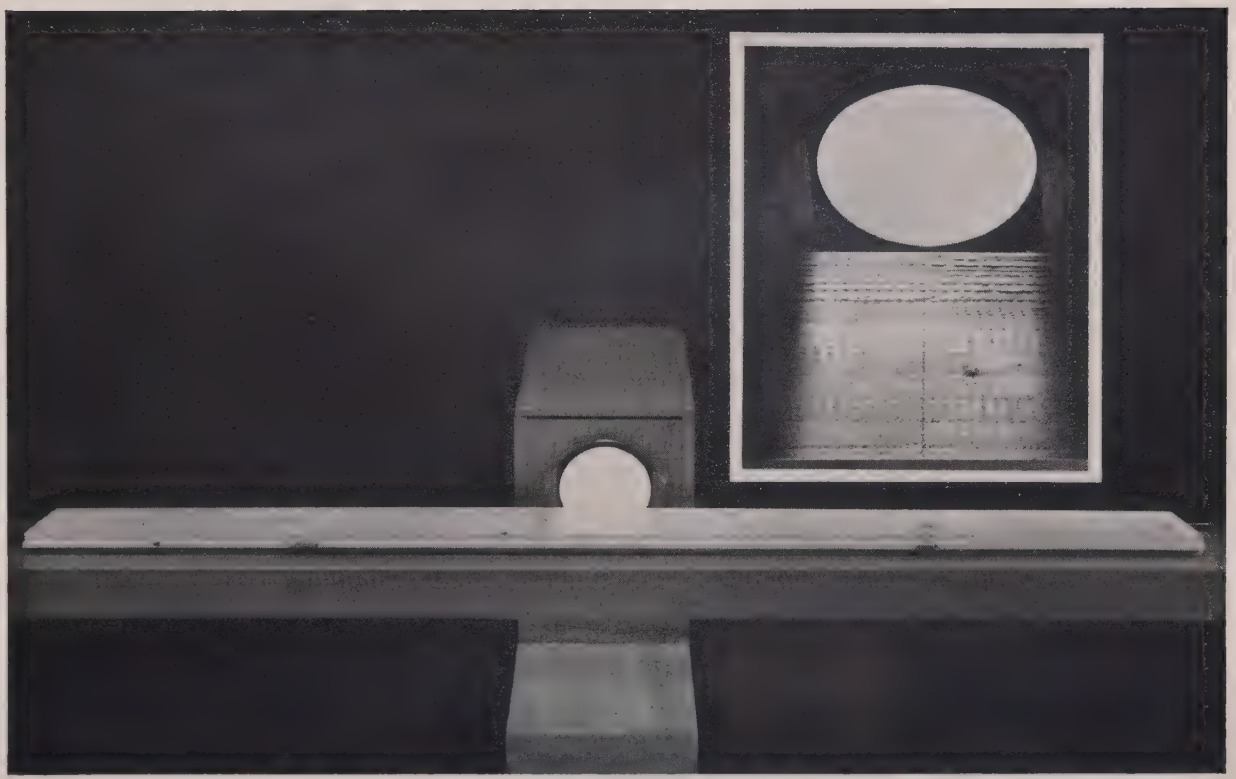
Laminated arches made from home-grown Sitka spruce

PLATE 4



Chip formation at a small depth of cut

PLATE 5



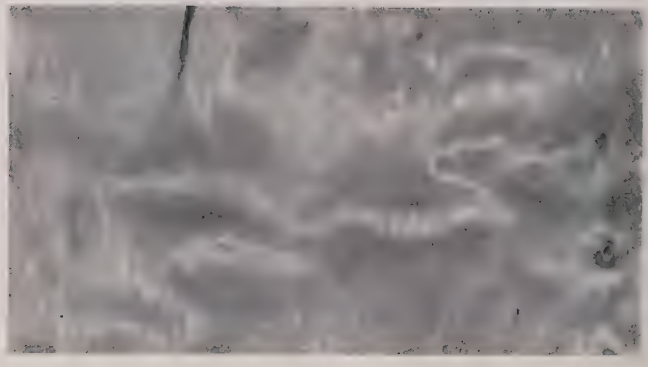
Illumination apparatus for assessing the machine finish of softwoods. *Insert* shows close-up of timber surface

PLATE 6

Butt billets for two rough and one smooth barked birch peeled to correlate bark form and veneer figure. *Left*—billet contained some flamy figure. *Centre*—billet contained figure associated with knots but no flamy figure. *Right*—billet contained straight grain and the veneer was unfigured.

PLATE 7

Flame



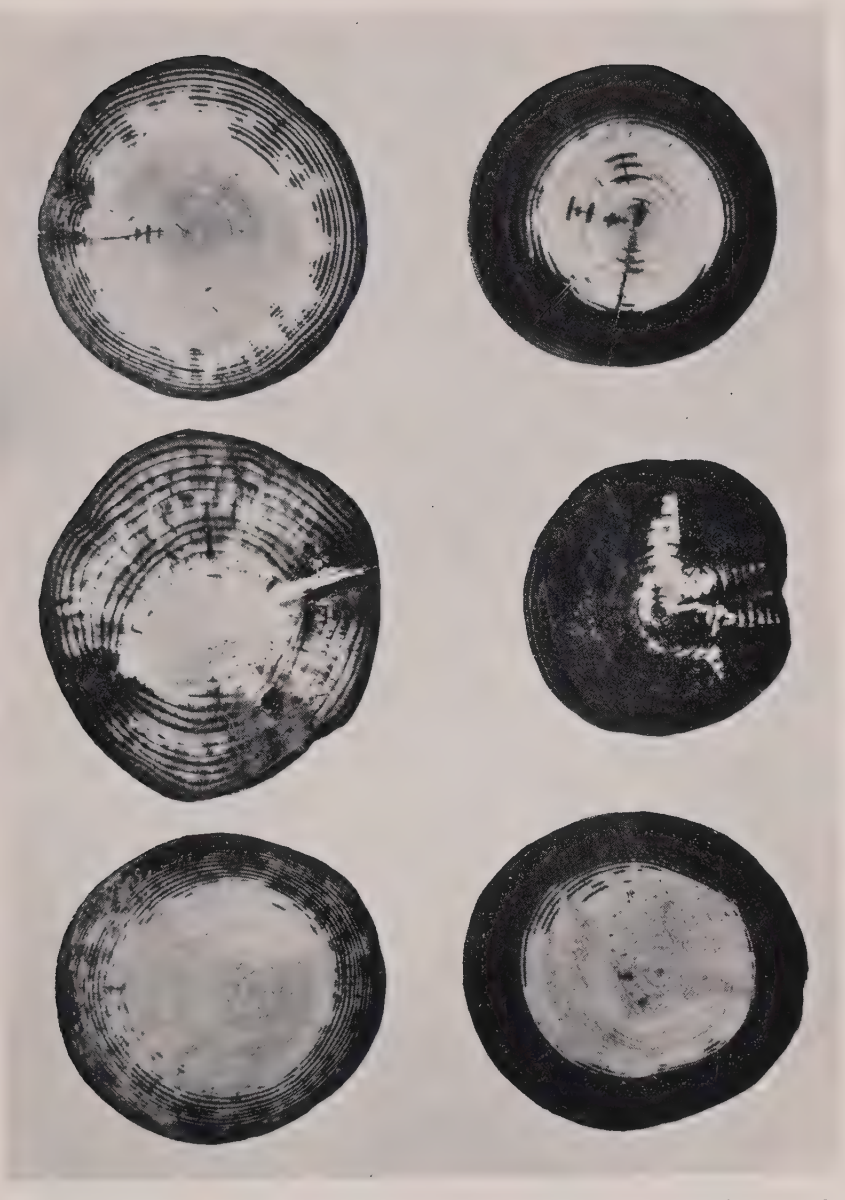
Wrinkle

Catspaw

Snail

Some of the types of figured veneer obtained from rough barked billets

PLATE 8



Not water stored *Stored in water for 6 months*

Top—Douglas fir
Centre—Sitka spruce
Bottom—Japanese larch

The effect of water storage on the preservative treatment of home-grown softwoods.

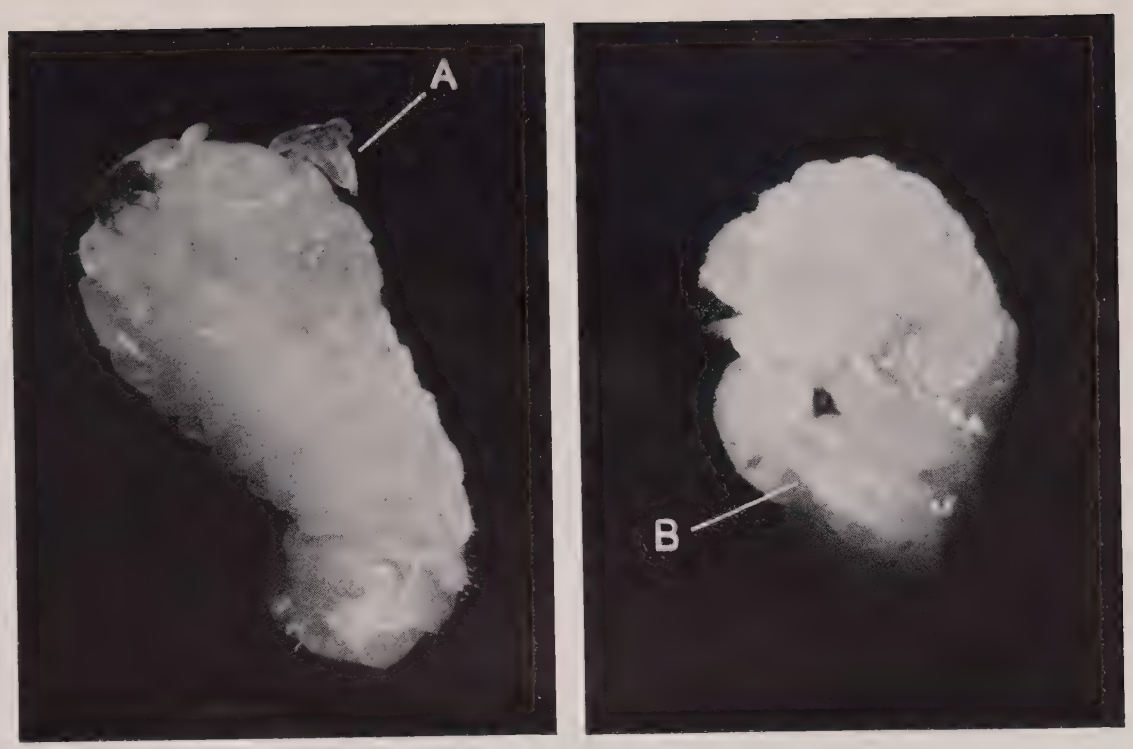
PLATE 9

Untreated logs with stained ends

Pentachlorophenol emulsion treated logs completely free from sap stain

Prevention of sap stain by end treatment of Scots pine logs. Logs felled in September after storage for three months.

PLATE 10



A: *Eggs*

B: *Larvae of the parasite*

Larva of *Anobium punctatum* attacked by the parasite *Theocolax formiciformis*

PLATE 11

(*Above*) Deep crack, and the scar visible on the bark after the wood has healed over the crack

(*Right*) Small cracks covering one or two growth rings, and usually 6 to 12 inches long

PLATE 12

Investigation into the reasons for these differences in penetration has shown that the depth to which a preservative penetrates during immersion is primarily a function of its viscosity and its surface tension. With some preservatives, however, other properties play a predominant part and work on this part of the investigation is still going on. A report on the work completed so far has been prepared.

MYCOLOGY

CULTURE COLLECTION

In view of the exceptionally dry weather and the pressure of other duties, collection of fungi in the field has been limited. Eight new cultures of wood-destroying Basidiomycetes have been added to the culture collection, one hundred cultures have been supplied to firms and research institutions, and some thirty cultures have been received for identification.

Co-operation with the Forestry Department of Kenya in the examination of decayed *Cupressus macrocarpa* has continued. A fungus isolated from one of the characteristic brown rots has been shown to be a white species of *Polyporus* by development of fruit bodies in culture.

PHYSIOLOGY OF WOOD-ROTTING FUNGI

Survival of Fomes annosus. Investigations to determine how long *Fomes annosus* can remain alive in naturally infected timber of Scots pine and European larch after the wood has been converted and dried (see Annual Report 1958, p. 29) have been completed. The results were similar in both timbers and indicated that the viability of *Fomes annosus* was greatly reduced after dry timber had been stored for seven months and that the fungus was no longer viable after ten months' storage.

Observations on experimental procedure. Preliminary trials of methods of growth of *Stereum sanguinolentum* in pure culture on test blocks have been carried out in preparation for testing the effect of this fungus upon the strength of softwoods.

In view of a possible need to carry out comparative durability tests with some of the less durable home-grown softwoods a number of preparatory tests have been undertaken. It has been shown that decay of non-durable Scots pine sapwood is more closely proportional to the volume of the test blocks than is decay of moderately durable Scots pine heartwood[27], indicating that in spite of the difficulty of obtaining uniform samples from selected zones in small trees care must be taken to ensure that variations in the dimensions of the samples do not arise. Experiments with *Poria monticola* which actively attacks softwoods have shown that test blocks exposed to this fungus must be placed on glass rests to prevent excessive uptake of moisture.

Stimulation of decay by chemicals. Stimulation of decay by the arsenic-tolerant fungus *Lenzites trabea* could not be detected in the presence of low concentrations of arsenic. No further work on the stimulation of decay by *Coniophora cerebella* in the presence of low concentrations of sodium fluoride has been carried out.

ROT IN WATER COOLING TOWERS

Lenzites sepiaria and a species of *Poria* causing a brown rot have been obtained from decayed water cooling tower timbers. The latter fungus is the

first brown rot reported to be causing extensive decay in waterlogged timbers in a water cooling tower in this country.

Gloeocystidium lactescens, originally isolated from waterlogged, decayed Scots pine in cooling tower mist eliminators causes only slow decay of beech and even less decay of Scots pine sapwood exposed to attack by the fungus by normal methods of malt agar culture, but when the moisture content of thin beech test blocks was controlled in soil bottles active decay took place. Maximum decay was obtained in test blocks conditioned to an initial moisture content of 60 per cent. As yet no indication of the characteristics which permit this fungus to attack waterlogged wood has been obtained.

EXAMINATION OF DEFECTIVE SITKA SPRUCE

A variety of discolorations in logs of home-grown Sitka spruce have been examined in the laboratory. Distinctive light brown colorations in the immediate vicinity of drought checks were not associated with fungal attack. However, where the checks had extended through the bark the coloration was more extensive and varied and a number of species of non-wood-destroying fungi (moulds) were present. Most of the other discolorations examined were irregular in their distribution across the log. They could be related to the presence of bark injuries or pruning wounds and mould fungi were frequently associated with them. Extensive and pronouncedly pinkish brown coloration was associated with the early stages of attack by the heart rot fungus *Fomes annosus* but in contrast no marked discoloration of the wood accompanied advanced decay by *Armillaria mellea* which was present in the extreme butt end of a few logs.

It was concluded that the causes of pinkish brown discolorations in Sitka spruce cannot be determined by examination of cross-cut surfaces but are best sought after conversion of defective material into boards. The majority of such discolorations may be ascribed to abnormal heartwood formation following injuries to the tree.

NATURAL DURABILITY OF TIMBER

Test fungi. In view of variations in decay resistance which commonly occur between the inner and outer heartwood of trees it is essential that samples from each zone should be tested as a matter of routine. To keep expenditure of effort on individual tests within reasonable proportions the use of fungi which consistently cause less decay has been discontinued and the number of test fungi employed in standard tests is now reduced from six to four. *Poria monticola* though causing active decay of softwoods has been shown to be unsuitable for testing of hardwoods. A recently isolated strain of *Lenzites trabea* has been shown to be much less active than the standard strain which has been in use for some years. The rate of decay by both strains can, however, be greatly increased by raising the temperature of incubation.

Natural durability of African mahogany. Laboratory tests on the natural durability of heartwood of *Khaya grandifoliola* have indicated that timber of normal density shows greater resistance to fungal attack than *K. anthotheca* and *K. ivorensis*, timbers with which it is marketed as African mahogany. Laboratory tests have also been carried out on the natural durability of ten other timbers.

Natural durability of larch. Limited tests on home-grown European larch and Japanese larch of comparable age (48 and 55 years respectively) have shown that variations occur in the decay resistance of samples of each timber taken

from different trees but that the overall resistance to decay of the two timbers may be broadly comparable.

Premature decay of western red cedar. Further work on causes of premature failure of the durable timber western red cedar when used in the manufacture of seed boxes has shown conclusively that, in contact with moist soil, toxic materials quickly leach out of thin pieces of the wood, so permitting marked attack by wood-destroying fungi to which the wood is normally resistant.

A toxic extractive from Indian rosewood. Agar tests have been carried out on a polyphenol which is present in the heartwood of the very durable timber Indian rosewood. The polyphenol is very toxic to wood-destroying fungi, concentrations of 0·03 per cent being sufficient to prevent growth.

WOOD PRESERVATIVES

No new work has been undertaken but the long-term tests of the residual toxicity of surface treatments (see the Annual Report for 1958, p. 31) have been continued. Treatments with creosote, 4 per cent sodium pentachlorophenate and 5 per cent sodium ortho phenylphenate remain effective after 30 months.

Information required for completion of the revision of the British Standard test of the toxicity of wood preservatives has been supplied. Wood block toxicity tests of the resistance to copper naphthenate, and pentachlorophenol of the strain of *Poria monticola* employed in American standard tests of wood preservatives are in progress.

Tests to determine the effectiveness of pentachlorophenol treatments of the bilge water in boats (see the Annual Report for 1957, p. 30) have been completed with disappointing results. No indication of protection against decay was obtained after 18 months of treatment, but it was found that in the moored house-boats chosen for the experiment little of the pentachlorophenol had passed into solution through the cloth bags in which it was held.

SOFT ROT INVESTIGATIONS

A paper describing the effects of *Chaetomium globosum* on the strength of beech wood in comparison with the effects of a white rot and of a brown rot fungus has been published[28]. In the Annual Report for 1957 (pp. 28–29) a short account was given of an investigation on the increased attack of Scots pine sapwood by *C. globosum* following heavy chlorination treatments. In view of possible misinterpretation of these results a full account of the work has been issued[29].

The problem of the manner in which soft rot attack occurs in softwoods under natural conditions has been kept under consideration but experimental work to reproduce attack in the laboratory has not been wholly successful. Scots pine sapwood blocks subjected to mixed infection by burial in unsterilised soil moistened with nutrient solution suffered 20 per cent loss of weight by soft rot attack in three months. In contrast similar blocks exposed in sterilised but otherwise comparable soil and inoculated with *C. globosum* lost only 2 per cent in weight. This provided some further indication that other organisms are more important than *C. globosum* as causes of soft rot of softwoods under natural conditions. The strain of *Sporocybe* which appeared to be the dominant organism on the severely decayed blocks exposed to mixed infection was isolated. This fungus was found to be an active soft rot organism causing 12 per cent loss of weight of beech in six weeks, but attack of Scots pine was restricted to the

extreme surfaces of test blocks and was so limited that it could not be recorded as a loss in weight. In view of the severity of attack in the limited zone in which it occurred it is considered that *Sporocybe* is a suitable organism for further experimental work.

Humicola grisea, a soil-inhabiting, cellulolytic fungus has been isolated from soft-rotted beech bait blocks and has been proved capable of causing soft rot of beech in pure culture but did not attack Scots pine sapwood.

Teak filling timbers from a water cooling tower in India and baulks of rock elm were among the more interesting samples of timber in which the presence of soft rot has been observed. The teak was the first sample of a very durable hardwood which has been examined after use in a water cooling tower. The extent of attack was negligible and the samples, after five years in service, appeared to be in excellent condition. In contrast the decay in the rock elm was very pronounced and bore a gross resemblance to severe attack by a brown rot fungus.

SAP STAIN INVESTIGATIONS

A survey of the incidence of sap stain in the forest areas of the East of Scotland was made during the month of July. *Ceratocystis pilifera* and *C. coerulescens* were the chief causes of stain in sawn Scots pine timber which had become severely stained whilst being air dried during the humid summer of 1958. Very dry conditions had prevailed prior to the visit and no appreciable staining of sawn timber had up to then occurred this year. Long delays between felling and conversion of Scots pine does not often occur in Scotland and, in contrast to experience in England, staining of timber whilst in log form did not appear to be a major problem.

The field experiment to determine the value of treating the ends of Scots pine logs with fungicides to prevent the entry of sap stain (Annual Report for 1958, pp. 31–32) has been completed. The appearance after storage for three months of the ends of untreated logs and logs treated with a pentachlorophenol emulsion is shown in Plate 10.

The efficacy of the treatments was assessed by converting the logs and assessing the extent of spread of stain in the wood. Treatment with 5 per cent pentachlorophenol emulsions gave good protection for three months and 4 per cent sodium pentachlorophenate was almost as effective. Logs felled and treated during spring and summer periods when the bark beetle *Myelophilus piniperda* was active were stained as a result of introduction of infection through the bark by the beetles. Spread of stain introduced by beetles rendered the end treatments ineffective in spring-treated logs which were stored for six months, but the chemicals noted above completely protected logs stored for six months after being felled and treated in September.

The fungi causing stain were grown in culture. Intense stains associated with beetle attack were caused by *Leptographium lundbergii*. In the latter half of the experiment this fungus also caused stain in logs which had been treated with concentrations of sodium pentachlorophenate lower than 4 per cent and which were not attacked by beetles. In these instances entry of the infection was through the treated ends. From less intense stains fungi known to grow on pine shoots and needles, such as *Diplodia pinea*, *Sclerophoma pithyophylla* and *Macrophoma strobi*, as well as species of *Phoma* as yet incompletely identified, and *Graphium piceae*, were isolated in culture. With the exception of *G. piceae*, none of the fungi commonly associated with staining in sawn timber were present, indicating

that the species of fungi causing stain in logs are different from those which are important as causes of stain after timber has been converted. Support for this observation was obtained when it was found that one series of logs had been extensively colonised by *Ceratocystis pilifera* a month after they had been converted for examination, though this common staining fungus was at no time isolated from logs immediately after conversion.

The fungi isolated were reinoculated on to clean Scots pine and it was confirmed that all gave rise to stains. Determinations of their rates of growth at different temperatures and of their resistance to commonly used anti-stain chemicals are in progress.

ENTOMOLOGY

AMBROSIA (PINHOLE BORER) AND LYMEXYLID BEETLES

West African investigations. Contact has been maintained with the West African Timber Borer Research Unit, and a programme of research has been prepared for the study of the biology of, and factors governing, attack by the Platypodid species, *Trachyostus ghanaensis* sp. nov. which damages standing wawa trees in Ghana.

Damage in coniferous forests, Argyllshire. Following a preliminary survey in 1958, when it was confirmed that *Trypodendron lineatum* (Scolytidae) and *Hylecoetus dermestoides* (Lymexylidae) were responsible for damage in softwood thinnings, periodic visits have been made in conjunction with staff of the Forest Research Station, Alice Holt Lodge, to experimental plots in the forests of Glenbranter, Glenfinart and Glen Duror. In each of these plots 144 Sitka spruce trees have been felled at the rate of 12 per month between November 1958 and October 1959 and left in situ, half being barked and half left unbarked (the normal practice). The results of incidence of attack and the habits of the insects are difficult to interpret: in Glenbranter no experimental stems were attacked although activity was present in logs nearby and in windblown stumps in the plot itself; in Glenfinart only two entrance holes were present but again attack was found in other logs in the vicinity; in Glen Duror, however, attack was heavier. In the Glen Duror plot attack by *Trypodendron* commenced in the latter half of April, reached a peak in the latter half of May and continued after July. Nearly all the entrance tunnels were found on three stems, and out of the remaining 129 stems felled before the September inspection, only 6 showed slight attack. The results indicate that (a) attack may commence soon after felling; (b) stems may remain susceptible over much of the season; (c) little difference exists between the susceptibility of upper and lower surfaces and along the length of the stems; and (d) barked material is much less liable to attack.

Owing to limited success in trapping beetles in plastic tubes placed over newly-made entrance tunnels, biological data were mainly obtained by the examination of infested stumps. Completed tunnels were found in July with larvae and pupae; others in September contained up to 20 pupal chambers, some with young adults. In September young beetles were detected boring into logs but to what extent this occurs is unknown. Generations evidently overlap.

Similar studies on *Hylecoetus* have been limited by the difficulty of detecting early stages of attack. Eggs are laid in the bark and some time elapses after larvae have bored into the wood before extrusion of dust becomes obvious. Only a single experimental log was attacked (one heavily infested by *Trypodendron*)

although elsewhere in the forest, attack was abundant. Bore dust first detected on 16th July was being copiously ejected in September. Comparison of larval sizes in the spring suggested the length of the life cycle can be two years.

A joint research programme for 1960 has been planned with the Forestry Commission. These investigations will be concentrated at Glen Duror and short billets utilised under more standard conditions than has been possible with long stems.

Lyctus POWDER-POST BEETLES

Starch depletion in kiln-dried and air-dried English oak in relation to infestation. Studies have been resumed on starch depletion and relative susceptibility to *Lyctus* attack in kiln-dried and air-dried boards (see Annual Report for 1956, p. 37). Boards were exposed to beetles for egg-laying in an outdoor insectary during the summers of 1957 and 1958, and information subsequently obtained on the extent of attack and ability of the insects to complete their life-cycle within material of various starch content gradings. All boards which showed no evidence of superficial infestation have now been re-exposed to attack at conditions of 25°C and 75 per cent relative humidity, in order to ensure that the beetles have had access to every board and to accelerate larval development which may occur. Data on starch depletion and on the susceptibility of the various boards to *Lyctus* attack have not yet been analysed.

Egg laying. A description of a technique described in the 1958 Annual Report (p. 33) has been published[30].

Prevention of infestation in sawn logs. Final examination of English oak boards treated in May 1955 has shown that a 10-second dip treatment in emulsions of DDT at concentrations of 1 and 2 per cent, and BHC or dieldrin at concentrations of 0·5 and 1 per cent, prevented attack during four years' storage out of doors. Attack occurred in some boards dipped in both concentrations of DDT and dieldrin after the treated surfaces were removed by planing. No attack was evident, however, in planed boards previously treated with BHC.

HOUSE LONGHORN BEETLE (*Hylotrupes bajulus*)

Occurrences. Some further occurrences have been reported but only in a few isolated cases have these been outside the more seriously affected areas in Surrey. With the co-operation of local council authorities all the records of attack in the United Kingdom known to them or to this Laboratory at that time have been published[31].

Biological studies. The ability of this insect to mate and breed under widely varying climatic conditions is being investigated. Suitable wood has been exposed to beetles in controlled, fluctuating conditions of temperature and humidity in rooms simulating wet tropical and dry tropical conditions. Eggs have been laid and the larvae have hatched in both cases.

Comparison has been made between the viability of eggs kept under constant temperature conditions at 25°C and 15°C. In each case approximately half of each batch of eggs hatched, though at the lower temperature the incubation period was considerably longer, and fewer larvae were able to establish themselves in the wood.

COMMON FURNITURE BEETLE (*Anobium punctatum*)

Behaviour and life-history studies. Further data have been obtained on the time of day at which females lay eggs under dwelling house conditions. It was found that the majority of eggs were laid between 12.00 noon and 5.00 p.m. in rooms with north-east and south-west aspects irrespective of differences in light intensity and temperature (which was continuously recorded). The time at which peak egg-laying occurs agrees with the results obtained from a previous experiment carried out in 1955 in the south-west room only.

Effect of fungal decay. Further beech experimental blocks decayed by soft rot to losses in weight varying between 7–14 per cent, exposed for egg-laying in 1957, have been cut up and it has been found that larvae also gained weight more rapidly in such material compared with the sound controls as found in previous experiments using less heavily decayed beech blocks. A progress report on the results so far obtained has been published[32]. It appears that soft rot reduced differences between the nutritional suitability of the three zones of beech selected, and the innermost zone (probably physiological heartwood) which, when sound, was found to be less suitable for larval development than the outer zones, became at least as suitable as the other zones following decay by soft rot. It also appears possible that soft rot renders wood surfaces more suitable for egg-laying and may facilitate the establishment of young larvae.

Effect of steaming. Steamed and unsteamed birch material exposed for egg-laying in 1957 has been cut up. These blocks matched to those described in the 1958 Annual Report (p. 35) and similarly treated have confirmed the previous data. In general the results show that treatments other than at 48°C for 1 hour, which had no apparent effect, rendered the wood progressively less suitable for larval development when the temperature was raised or the duration of the treatment was lengthened.

Obeche plywood. Previous studies have indicated that obeche is unsuitable for larval development (see Annual Report for 1957, p. 33). An experiment to ascertain the effect of making up plywood with $\frac{1}{8}$ in. obeche veneers and blood-casein glue, which is known to facilitate larval development in birch or alder plywood, has been undertaken. Obeche plywood made up with this glue, and with urea formaldehyde glue for comparison, and exposed for egg-laying in 1957 has been cut up. Although a satisfactory number of eggs had been laid it was found that no larvae had survived in the plywood made up with either glue nor in the solid wood controls. It thus appears that the use of blood-casein glue (which would increase the nitrogen content) in the case of unsuitable wood species, may not render them susceptible.

Nutritional studies. A summary has been published of the studies carried out over recent years on the effect of zoning and extracting with various solvents Corsican pine, Scots pine and European oak, and their resultant susceptibility to attack by *Anobium*[33].

DEATH-WATCH BEETLE (*Xestobium rufovillosum*)

Biological studies. A description of the secondary sex characters detected in this species and briefly mentioned in the Annual Report for 1958 (p. 36) has been puplished[34].

Supply of test insects. Through the co-operation of the Chief Architect, Ministry of Works (Ancient Monuments Division) collections of death-watch

beetles from Eltham Palace and Westminster Hall have been sent daily to the Laboratory. Beetles thus obtained in much larger numbers than can be conveniently reared in the laboratory have been used for a variety of purposes, including preservative tests and general cultures, and have enabled a record to be made of the daily ratio of the sexes throughout the emergence period. For irradiation and fumigation tests, where it has been necessary to obtain beetles prior to emergence or to know their precise age after emergence, a useful source of supply has been the naturally infested, decayed parts of willow trees located in the riverside districts of Oxfordshire.

Field observations

(a) *King's College Chapel, Cambridge*. Further studies have been undertaken on the emergence of beetles from the roofing timbers and their distribution has been plotted (Annual Report 1958, p. 36). The data confirm those previously obtained.

(b) *H.M.S. Victory*. The number of death-watch beetles collected this summer (the third emergence period since the last fumigation of the ship in 1956) was 65 as compared with 74 in 1958 and 72 in 1957. Recommendations have been made to and accepted by the Victory Advisory Technical Committee that any further fumigation treatment should be deferred until the completion of the present repair programme, which requires the removal of much of the damaged and decayed wood. It is of interest to note that the numbers of the predatory beetle *Corynetes coeruleus* collected, which reached a peak of 548 in 1955, dropped to 2 this year. The numbers in 1957 and 1958 were 197 and 40 respectively. It is well known in predator/prey relationships in general that a drop in the numbers of predators usually occurs in arrear of a fall in the numbers of the prey. The figures for *Corynetes*, therefore, provide further evidence of a considerable drop in the death-watch beetle population.

PARASITES

Work has been started on the parasites of *Anobium punctatum* to investigate their role in the natural control of this pest. There is little information available on this subject, apart from studies by Becker and Weber on *Theocolax formiciformis*[35] and by Lygnes on *Spathius exarator*[36] and on *Plutothrix coelius* (*Trigonoderus tristis*)[37].

It appears that in this country *Theocolax* is the commonest hymenopterous ecto-parasite of *Anobium* larvae (see Plate 11) and life history studies have accordingly been started on this species. It has been found that, during the summer months under out-of-door conditions, the life cycle occupies 10–12 weeks, which is divided up approximately as follows: incubation of eggs 1–2 weeks, larval development 3 weeks, a resting period of 2 weeks and a pupal stage of 3–4½ weeks. Adults emerging from infested wood lived 3–4 weeks. It is not yet known how many generations are produced in one year and further investigations are planned.

A second chalcid parasite collected from *Anobium*-infested birch plywood has been identified by the Commonwealth Institute of Entomology as *Plutothrix coelius* (Walker), which is a comparatively rare species in Britain[38].

TOXICITY OF METHYL BROMIDE TO WOOD-BORING INSECTS

Studies on the effect of such fumigation on different developmental stages of wood-boring insects have been continued in co-operation with the Pest Infestation Laboratory.

Death-watch beetle. Tests carried out in 1958 showed that dosages expressed as a concentration-time product of 50, 60 and 70 mg h/l prevented egg-laying by beetles treated soon after mating, but that the beetles survived for long periods. These tests have been repeated using the same dosages but with a greater interval between mating and treatment, i.e. treatment was carried out near to the time at which normal egg-laying would be expected to commence. These results confirm that the beetles survive for appreciable periods but in spite of this only a few fertile eggs were laid by those treated at the lowest dosage.

Woodwork of buildings in the Round Tower, Windsor Castle, infested by the death-watch beetle was fumigated with methyl bromide by a commercial firm in April. Gas sampling was carried out by the Fumigation Section, Pest Infestation Laboratory. Data were obtained by the Forest Products Research Laboratory on the numbers, distribution and condition of beetles before and after the treatment. Arrangements have been made with the Ministry of Works for further annual examinations to be carried out.

Common furniture beetle. Further work has been carried out on the toxicity of methyl bromide to common furniture beetles. Only the highest dose of 200 mg h/l used throughout all the tests has consistently prevented emergence of beetles by killing both larvae and pupae. Inconsistent results obtained for lower dosages are probably due to variations in the condition of the boards in respect to the extent and distribution of damage and the numbers and location of the insects. Experiments on such material have, however, many advantages over fumigation of larvae and pupae removed from the wood, since they more closely resemble commercial practice and enable results to be expressed in terms of emergence of adults, which is the criterion normally employed in assessing the effectiveness of such treatments.

The house longhorn beetle. Eggs have been fumigated at a series of dosages between 50 and 200 mg h/l. The results show that the dose necessary to prevent hatching lies between 50 and 75 mg h/l, which is in close agreement with the data obtained for eggs of the common furniture and death-watch beetles in previous experiments.

LABORATORY TESTS OF WOOD PRESERVATIVES AND INSECTICIDES

Contact insecticides. Further tests with death-watch beetles have shown that an exposure period of 48 hours to dieldrin deposits of 0·04 mg/sq. cm are necessary to prevent egg-laying when the beetles are transferred to untreated, decayed, oak sapwood.

Preservative tests.

(a) *Death-watch beetle.* Tests were carried out in 1956 and 1957 with English oak sapwood dipped for 10 seconds in a number of solutions and exposed subsequently to egg-laying by the death-watch beetle (see the Annual Report for 1956, p. 42, and 1957, p. 37). Treated blocks from these tests which had previously resisted infestation were re-exposed in 1959 and it has been found that all materials remained effective in either preventing egg-laying or hatching or successful larval penetration into the wood.

(b) *Common furniture beetle.* Scots pine sapwood blocks dipped for 10 seconds in solutions of dieldrin and BHC at concentrations of 0·5, 0·3, 0·1 and 0·05 per cent were exposed to common furniture beetles for egg-laying. Although a very small number of eggs were laid on one block dipped in 0·05 per cent

dieldrin solution and on one dipped in 0·1 per cent lindane, none hatched. Viable eggs were present on blocks dipped in white spirit, but fewer than on the untreated control blocks.

GAMMA RADIATION TREATMENTS

In co-operation with the Radiation Chemistry Group, Atomic Energy Research Establishment, Harwell, and the Technological Irradiation Group of the Isotope Division, Atomic Energy Research Establishment, Wantage, studies have been continued on the effect of gamma radiation on the developmental stages of four species of wood-boring insects.

Results of particular interest are those concerning the eggs of the common furniture beetle. Previous data showed that eggs in which embryonic development was advanced were extremely resistant to radiation, and doses in excess of 96,000 roentgens (r) were needed to prevent hatching. A total of 794 eggs of known age (13 to 21 days old at the time of treatment) have been irradiated at a series of dosages between 6000 r and 20 000 r, but only four eggs, 19 days old, irradiated at 8000 r hatched, whereas 39 of the 50 untreated control eggs of similar ages were viable. The limits of the incubation period of the controls were 22 to 33 days. The greatly increased susceptibility of these mature eggs to gamma radiation compared with previous results is thought to be due to conditions of storage. Previous experiments have been conducted under out-of-door conditions but, in this instance, they were carried out indoors in a non-insulated wood hut in which high temperatures were recorded during the unusually hot weather prevailing. Such an adjuvant effect of high temperature in increasing the potency of gamma radiation has not been previously noted in the case of wood-boring insects, although a similar effect was detected in the chalcid *Dahlbominus fuscipennis* by Baldwin and Narraway, who found that the killing power of X-rays on the females was greatly increased if higher than normal temperatures were applied after treatment[39].

The results for death-watch larvae are somewhat variable. A few beetles emerged from the naturally infested elm and willow, possibly as a result of failure to obtain an accurate and uniform dosage in all parts of the irregularly shaped material, unlike the small oak blocks into which larvae had been transferred.

Examination of eggs laid by death-watch beetles irradiated in the autumn of 1957 at an early stage in their hibernation, at dosages from 6000 r to 15 000 r, has been completed and the results of egg-laying and hatching examined statistically. Results quoted in the 1958 Annual Report (p. 40) showed that eggs laid by beetles, when both sexes have been irradiated at and above 10 000 r and then mated together, did not hatch. Completed data now show that when treated beetles were mated with untreated specimens of the opposite sex, a few fertile eggs (approximately 1 per cent) were laid even at the highest dosage.

STERILIZATION OF INSECT-INFESTED WOOD

(a) *By infra red heating.* Further experiments carried out with naturally infested birch plywood showed that when the temperatures on the unheated face of the wood exceeded 55°C a larval mortality of 100 per cent was reached. This is comparable with the data previously obtained for *Lyctus* in obeche plywood (see Annual Report 1956, p. 44) but lower than that found necessary in the case of *Lyctus*-infested oak where 60°C caused less than 100 per cent mortality.

(b) *By radio frequency treatment.* The results of these investigations have been published[40]. No further investigations are being undertaken until fresh lines of research have been discussed more fully.

MISCELLANEOUS WORK IN ENTOMOLOGY

An unusual type of enquiry has been the incidence of sawfly attack during the latter part of 1958 from various new school buildings in Warwickshire. These insects bored into the exterior wall cladding (principally western red cedar) and in some cases into interior plasterboard partition walls. The larvae were identified as *Ametastegia glabrata* by the British Museum (Natural history). The larvae of this common British sawfly live chiefly on dock, rhubarb and buckwheat and when fully grown change into pre-pupae which seek out and tunnel into soft materials, such as wood, pith, apples, etc., where they spend the winter before changing into adults the following spring. In the present instance it seems possible that the insects found in the cladding may have come from docks growing in the recently disturbed soil round the new buildings. The damage caused by an individual pre-pupa is not extensive, and the maximum tunnel length is likely to be about the same as the insect's body — approximately $\frac{3}{4}$ in. The numbers of insects concerned were, however, very large. The use of a 2 per cent oil/water emulsion of DDT was recommended to discourage further boring. A note on these occurrences has been published[41].

CHEMISTRY

WOOD EXTRACTIVES

Indian rosewood. Studies of the crystalline phenolic substance from this timber (see Annual Report for 1958, p. 40) have indicated that it is probably either a diphenylmethane or a diphenyl derivative. Further work on the constitution of the compound is in progress in collaboration with University College, Dublin.

Extractives of timbers of the family Moraceae. Investigation of the extractives of Moraceae timbers has been continued (see Annual Report for 1958, p. 41) and a paper describing the results obtained has been published. Crystalline dihydromorin and dihydrokaempferol have been isolated from both mulberry and fustic while an extract of osage orange yielded dihydromorin penta-acetate on acetylation. Neither maclurin nor 2,4,6,4′-tetra-hydroxy-benzophenone could be detected in the heartwood of mulberry, although previous workers had isolated both components from the branchwood. This difference of results may be due to variation within the species or to the fact that different parts of the tree were used in these experiments.

Of particular interest was the identification of the "cudranin", previously isolated from mulberry, as 2,4,3′,5′-tetrahydroxystilbene. This is in agreement with the results of Kondo, Ito and Suda[42], who isolated it from *Morus bambycis* (*Morus bambycis*=*M. alba* var. *stylosa* Bur.). This stilbene has also been obtained by other workers from the Moraceae timbers osage orange, *Artocarpus lakoocha* and *Cudrania triloba;* the 4′-substituted derivative, chlorophorin, occurs in iroko.

WOOD POLYSACCHARIDES

Hemicelluloses in beech. Since the previous report on this subject (see Annual Report for 1957, pp. 39–40) only a relatively small amount of time has been devoted to this topic, but some advances have been made. Hydrolysis of ex-

tractive-free beechwood yielded a mixture of sugars in which L-fucose was identified by the formation of the crystalline p-toluene sulphonylhydrazone (cf. Annual Report for 1956, p. 45). Also present in the hydrolysate were very small amounts of methylated sugars, tentatively identified as 2-*O*-methyl xylose and 2-*O*-methyl fucose. Work on the separation of these components is in progress.

PRODUCTION OF FIBREBOARD FROM COLONIAL TIMBERS

An investigation on a laboratory scale has been made of the utilization of four timbers from North Borneo for production of hardboard. The timbers tested were kapur, keruing, red seraya and white seraya. Timbers grown in Malaya and closely allied to two of these, viz. keruing (*Dipterocarpus crinitus*) and red meranti (*Shorea leprosula*), have already been included in a previous investigation, but special interest was expressed in the Borneo varieties and particularly in the possible use of mixtures of red and white seraya.

The Asplund Defibrator process was applied to each of the four timbers individually and to a mixture of equal proportions of red and white seraya. Defibration was carried out under various conditions of temperature and pressure, without any chemical treatment, and boards were pressed from the resulting pulps using a variety of pressing conditions. It was found possible to make boards which met the requirements of B.S. 1142 : 1953 for standard and super hardboard from each of the woods without further refining of the Defibrator pulp and without addition of any chemicals or sizing material at the sheet-forming stage. This result was obtained by pressing the boards at a suitably high temperature with rapid application of pressure, together with a hot air treatment of the boards after pressing to reduce their water absorbency to the required level. Very rapid attainment of maximum pressure on the wet mats in the press was possible owing to the high degree of freeness of the pulps. This has a beneficial effect on the strength properties of the boards which offset any inherent weakness which might have resulted from the unrefined nature of the pulps.

The appearance of boards made from kapur tended to be marred by dark coloured patches on the surface. This was found to be due to deposition of water-soluble materials, peculiar to this species, during evaporation of water in the press, and could be avoided by a very thorough washing of the pulp before forming the wet mat. In large-scale operation this would considerably increase the water consumption and might be considered a disadvantage in the use of this timber.

The keruing tested had interlocked grain which resulted in uneven thickness of the chips and consequent increased resistance to defibration. While the fibre produced appeared satisfactory, the power consumed in defibration may be expected to be high as a result of this characteristic of the wood.

In general, red seraya proved to be the most satisfactory of the four timbers tested, while the mixture of red and white seraya presented no special problems.

PULP AND PAPER RESEARCH

A considerable amount of time has been devoted to preparations for setting up a new pulp and paper section at the Laboratory. Visits have been made to other organizations engaged in research on pulping and papermaking in order to obtain advice concerning apparatus and equipment for laboratory work and experimental methods and techniques.

Evaluation of the pulping and papermaking characteristics of a raw material

comprises the following steps: chipping; digestion according to a previously selected process; screening the pulp; beating for a range of times in a standard type of beater or mill; sheet-formation under carefully standardized conditions from the unbeaten and beaten pulps; and conditioning and testing of the paper sheets (basis weight, bursting strength, tensile strength, tearing resistance, folding endurance).

Plans have been drawn up for adapting the building that is to form the pulping laboratory and most of the equipment for digestion, screening, beating and sheet formation has been delivered. Paper testing must be carried out under accurately controlled conditions of temperature and humidity. A room has been constructed for this purpose and air-conditioning equipment installed and the necessary paper testing machines obtained. The essential equipment for commencing laboratory work has thus been acquired and, although the pulping laboratory was not yet ready for occupation, it was possible to make a start using temporary accommodation before the end of the year.

During the year members of the staff of the Laboratory worked for varying periods of time at the Tropical Products Institute, in order to assist with laboratory work on pulping home-grown timbers in progress there and to receive training in the methods and techniques involved in routine pulp evaluation work. Simultaneously, analytical work has been carried out at the Forest Products Research Laboratory on wood samples taken from some of the logs that were provided for the pulping trials at the Tropical Products Institute.

GENERAL WORK IN CHEMISTRY

An investigation has been commenced to determine the effect of treatment with chlorine on the susceptibility of wood to attack by soft rot fungi. A preliminary experiment (see the Annual Report for 1957, p. 29) had indicated that chlorination of wood under rather drastic conditions may accelerate the subsequent growth of *Chaetomium globosum* on the wood. This experiment is now being repeated using a less severe chlorination treatment which approaches more closely to the conditions that may arise in water cooling towers. The tests include two levels of concentration of chlorine and two periods of time, and it should be possible to determine from the results whether and to what extent exposure of wood to low concentrations of chlorine promotes the growth of soft rot fungi on it.

The advisory work of the Section covers a range of topics similar to those dealt with in previous years (stains, deposits, irritant properties of timbers, bleaching, corrosion of metals, use of timbers for specific purposes, etc.). A number of enquiries has been received concerning the elementary composition of woods to be used as radiation shields in atomic energy establishments, because the absorption of radiation depends largely upon the hydrogen content of the material.

A further instance of the harmful effect of the presence of salt in wood has arisen. In a large number of emergency beds constructed of ramin framing covered with canvas, corrosion of the tacks holding the canvas occurred due to the presence of salt in the ramin, and resulted in tendering of the canvas around the tacks. The occurrence of salt in ramin had not previously been reported.

PHYSICS

MOISTURE RELATIONS

Using a vacuum sorption apparatus, equilibrium moisture content curves have been obtained in adsorption and desorption for the following timbers: afzelia, muninga, Andaman padauk, muhuhu, ekki, teak, afrormosia, ayan, opepe, East African camphorwood, red louro, iroko and Sitka spruce (3 independent runs). Concurrently with these measurements, corresponding results for 16 timbers were published by Spalt[43], who took the well known sigmoidal relationship between moisture content (r) and relative humidity (h) to be represented by the semi-empirical equation,

$$A+Bh - Ch^2=h/r,$$

where A, B and C are parameters, the values of which are calculated from experimental results by the method of least squares. Values of A, B and C obtained here for teak are compared with Spalt's values in Table 3, which also contains the constants for Sitka spruce from the individual runs and from all three runs taken together.

Table 3

Adsorption and desorption parameters for teak and Sitka spruce

Species		Adsorption or desorption	Source	Temp. °C	Parameters		
					A	B	C
Teak		Adsn.	Spalt	32	2·94	13·63	11·87
			F.P.R.L.	27	1·98	18·51	16·05
		Desn.	Spalt	32	3·11	7·64	6·23
			F.P.R.L.	27	2·37	9·49	7·26
Sitka Spruce	1	Adsn.	F.P.R.L.	27	2·93	11·44	10·22
		Desn.			2·16	9·60	8·06
	2	Adsn.	F.P.R.L.	27	1·59	15·79	13·84
		Desn.			1·97	10·00	8·72
	3	Adsn.	F.P.R.L.	27	2·33	12·33	10·90
		Desn.			1·30	12·54	10·51
	All	Adsn.	F.P.R.L.	27	1·92	14·59	12·80
		Desn.			1·70	11·04	9·35

Figs. 7 and 8 show the present experimental results and the curves for teak and Sitka spruce. The measurements are evidently represented very closely by the equations, and there is little difference between Spalt's curves for teak and those obtained here. The numerical values of corresponding parameters, however, differ markedly, not only for the teak, but also for the different runs on the Sitka spruce. It is therefore possible to obtain closely similar curves from equations in which the numerical values of corresponding parameters differ appreciably, and the individual values of the parameters cannot by themselves characterise the sorption behaviour of timbers.

In view of the lack of knowledge of wood water relationships near to and above the "fibre saturation point"[44] possible methods of investigating this

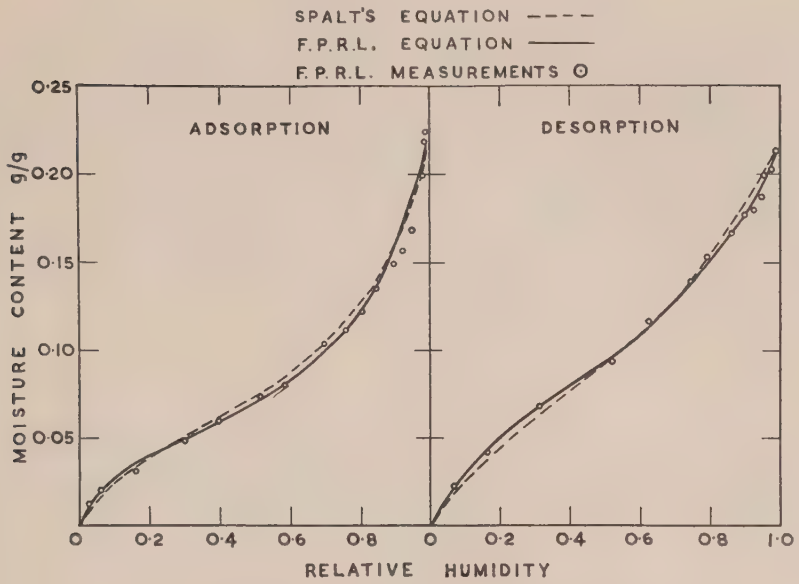


Fig. 7. Equilibrium moisture content curves for teak.

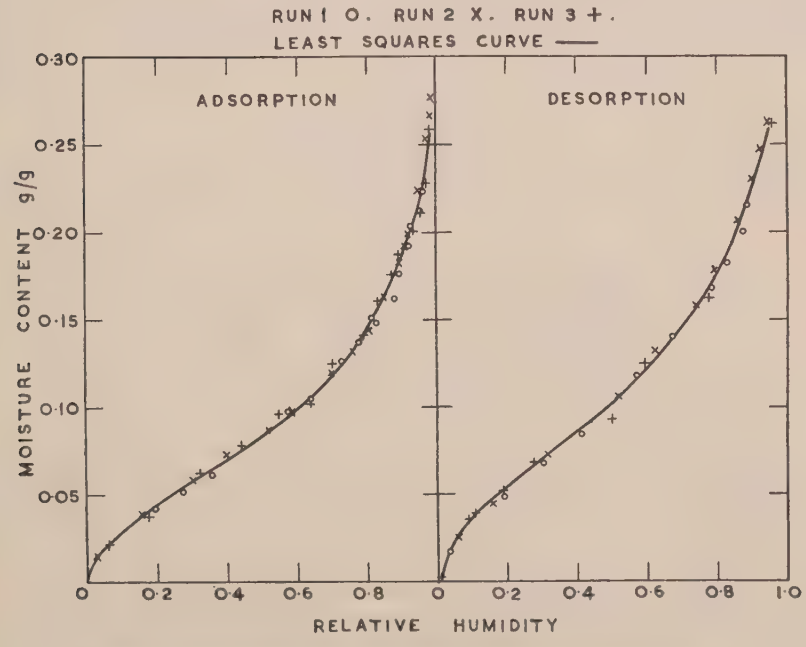


Fig. 8. Equilibrium moisture content curves for Sitka spruce.

region have been under consideration, and during the past year a few measurements have been made on freezing point depression of the water in wood, and on moisture content as affected by applied suction. Neither method has proved very successful. Except over a very limited range of moisture contents, the suction method fails for solid wood, because of the distortion which occurs as soon as any moisture is lost, and gives results of doubtful utility when applied to sawdust because the moisture holding properties are influenced by the size of the sawdust particles. This factor also affects the freezing point depression which, in addition, is difficult to measure accurately and is influenced by the presence of soluble salts. A technique has been developed recently at Road Research Laboratory for studying soils in the high moisture content region by means of a pressure-membrane apparatus[45] and it is intended to try this technique on wood during the coming year.

SPECIFIC HEAT OF WOOD

On the basis of results obtained in 1912 by Dunlap[46], it has hitherto been accepted that the specific heat of wood is independent of species and has the value 0·29 cal/g at about 20°C. Dunlap used a Bunsen ice calorimeter in his experiments, and his results have been confirmed by Koljo[47] using a method which depends on the rate of cooling of the material, and by other workers. More recently, however, results have been reported which differ substantially from Dunlap's. Narayanamurti and Jain[48] for instance, using a cooling method on nine Indian timbers obtained values varying from 0·31 to 0·41. In view of these discrepancies, measurements have been made here on sawdust from specimens of four of the species used by Narayanamurti and Jain, using the same cooling method as these workers. The values are compared in Table 4.

Table 4

Specific Heat of Indian Timbers

Species	Narayanamurti & Jain	F.P.R.L.
Cedrela toona	0·41	0·35
Calophyllum spp.	0·40	0·33
Canarium	0·31	0·35
Andaman padauk	0·35	0·31

The present values tend to be lower and less variable than those of Narayanamurti and Jain, but they are appreciably higher than Dunlap's values. Re-examination of Dunlap's results shows that he rejected some of his observations by a statistical test, the validity of which is doubtful. If these rejected observations are taken into account, the mean value is lowered slightly and the standard deviation is approximately doubled. This, however, is still insufficient to account for the discrepancies, and it appears that the variation in specific heat between timbers of different species may be larger than has hitherto been accepted.

VIBRATION OF PLYWOOD PLATES

An exact and detailed mathematical analysis has been published by two American workers[49] of the vibration of rectangular plates having the type of elasticity appropriate to plywood, and having two opposite edges simply supported. The remaining two edges can then be either both free, both supported, both clamped, one free and one supported, one free and one clamped or one supported and one clamped. Using methods developed here, approximate values of the frequency constants have been calculated for each of these six cases, and comparison with the values obtained by the accurate analysis shows excellent agreement. A note on this work has been published[50].

MISCELLANEOUS WORK IN PHYSICS

External enquiries regarding thermal conductivity, thermal expansion, electrical conductivity, swelling pressure and coefficient of friction of wood have been dealt with.

Application of statistical methods to the following problems has been discussed with members of the appropriate section and work carried out on the problems as required: effect of irradiation and other treatments on death-watch beetle; analysis of variance and covariance in Forestry Commission experiments; design of Latin squares; number of specimens required in mycological durability tests; determination of limiting radius of bending.

EXTERNAL RELATIONS

A total of 6061 cu. ft of round and sawn timber was received at the Laboratory during the year. It consisted of 1405 cu. ft of imported hardwoods, 60 cu. ft of imported softwoods, 3712 cu. ft of home-grown softwoods and 884 cu. ft of home-grown hardwoods. The total is approximately the same as that of the previous year but the amount of home-grown timber has increased by nearly 600 cu. ft.

GENERAL TESTS

Reports on the general properties of the following timbers were completed and circulated: *Dipterocarpus caudiferus* and dark red seraya from North Borneo, and *Khaya anthotheca* from Ghana.

TIMBER QUALITY IN RELATION TO SILVICULTURE

Reports on Japanese larch and European larch were completed during the year but no further work is contemplated in the immediate future on this series of experiments on home-grown timber, which was started seven years ago.

Tests on home-grown Sitka spruce from four different provenances of seed, viz. Queen Charlotte Island, Washington, Oregon and California, indicated that timber from trees grown from Queen Charlotte Island seed was appreciably denser than that grown from seed from the other three places. Trees grown from Washington, Oregon and California seed yielded timber of similar densities. The material was young and further investigations would be required to confirm these results.

INVESTIGATIONS ON HOME-GROWN SITKA SPRUCE

General. Work is being carried out on the properties of sawmill size timber of Sitka spruce from various sites and quality classes. Fifteen consignments each of ten trees ranging in site distribution from Devon to the south of Scotland have so far been received for testing.

Log grading. A method has been devised of grading the logs into three groups by taking into account the straightness, length, and incidence of knots. It is hoped to show that this external grading of logs can be correlated with the graded material obtained from the converted logs.

Occurrence of cracks. The logs were sawn up for general test and any defects or peculiarities in the timber were noted. The most serious defect was the prevalence of cracks which occurred across the growth rings of the tree. They occurred in about 20 per cent of the trees examined. It was realised that this defect would have a major effect on the quality of the sawn material and special notes were made whenever possible concerning the type of crack and the extent. Three distinct types of crack occurred: first, deep cracks which may extend up the tree for a considerable distance, one measured being over 20 ft in length. These cracks are usually found in the Quality Class I and II trees which have grown quickly and the scars from the cracks can be distinctly seen on the bark (see Plate 12a). Secondly, there are cracks that are smaller in depth cutting across 3 to 6 growth rings and only a few feet long. They sometimes occurred at various heights in a tree. Thirdly, where wide growth rings have been formed, the cracks are many but not deep and only 6 to 12 in. long (see Plate 12b). From a commercial point of view the effect of any of these cracks can be a serious degrade on the sawn material; as most of the timber had a steep spiral grain the cracks sloped across the planks and could not be cut out. Further special studies would be required to elucidate the cause of these cracks.

Density relationship within the tree. Work has been concentrated on the specific gravity pattern, and its associated factors, in Sitka spruce. Samples have been taken from the consignments of Sitka spruce referred to above. A minimum of five trees has been sampled from each site, samples usually being taken at five heights in each tree.

The specific gravity pattern across the section of a tree was found to be very consistent. A high value was obtained for the first five years of growth and the lowest value occurred between ten and fifteen years. From fifteen to thirty years the specific gravity increased fairly steadily on average, with a limited rise and fall in some trees. There was no indication of a relatively constant value being reached within thirty years.

The influence of height on specific gravity was examined on thirty trees. The effect of height alone was not shown by differences in the specific gravity of whole cross-sections, since the influence of the relationship to the centre is an overriding factor. The higher the cross-section is cut, the greater will be the influence of the large volume of low-density material formed between five and twenty years, thus giving a false picture of decrease in density with height, often with an apparent increase near the top of the trees where the small volume of high density material of the first five years of growth has more effect. It was therefore decided to consider the outside five growth rings only, since they had been formed at all heights in the same period of the life of the tree. The results, allowing for the fact that these same five growth rings gradually approach the centre of the tree with increasing height, show that height alone, when other factors are eliminated, has little, if any, influence on specific gravity.

The rate of growth in terms of ring width, or rings per inch, and its effect on specific gravity, is being studied. A first examination of the results shows the relationship to be fairly good within a consignment but the overall relationship of specific gravity to rate of growth for a given quality class or for the species

as a whole has yet to be finally determined from the figures available. It does not appear, however, that the relationship will be sufficiently marked for rate of growth alone to be used as a guide to density except within fairly wide limits. Other factors, notably the influence of the dense summer wood (see below) and possibly that of the intermediate wood, to some extent mask the relationship.

It seems clear, however, that the change in density across the section of any one tree from five to thirty years is fairly closely linked with changing ring width, very wide growth rings occurring between five and fifteen years at all heights, where the specific gravity is low. One consignment, of trees which were slow-grown for the first fifteen years, showed confirmation of this, since the specific gravity values at the butt for those years were exceptionally high.

The effect of this volume of fast-grown, low-density material in the majority of plantation-grown trees should not be overestimated in terms of a final crop, since it has a much greater influence on the overall values for the thirty-year-old trees examined than it would have later if the level of specific gravity reached at thirty years were to be maintained.

The work for this investigation will be completed with the examination of fifteen trees from the north of Scotland and only then will it be possible to draw more definite conclusions from the information available.

Influence of summer wood on density. The amount of summer wood, measured in actual width and as a percentage of the growth ring, has been determined upon the butt discs of every tree used in the investigation into specific gravity. Only the dense zone of summer wood at the end of the growth ring was measured, since the visual limits of the intermediate zone between summer wood and spring wood that occurs in the majority of growth rings in this species were too indistinct.

In any one group of five growth rings, the summer wood was found to vary between 5 and 40 per cent, but the average values for each consignment ranged only between 10 and 15 per cent. Within individual growth rings variation in the percentage of summer wood appears to be closely and linearly related to the number of rings per inch at any period of growth including the first five years. Comparisons between consignments of different quality classes and from different parts of the country will be made when the present investigation is completed.

The variation in percentage of summer wood at different heights up the tree was examined in two consignments, the Quality Class I from Haldon, Devon, and the Quality Class III from Coed-y-Brenin, North Wales; a third will be selected from the consignments from North Scotland. No significant difference was noted at different heights other than that associated with changes in the rate of growth.

Detailed study of the relation between percentage summer wood and specific gravity in individual growth rings was made on butt discs of two consignments, the Quality Class V trees from Halwill, Devon, and the Quality Class III trees from Coed-y-Brenin. Those from Halwill had a high specific gravity being very slow grown for the first twenty years and containing a high percentage of summer wood

The detailed investigation into the specific gravity of individual rings and their separate zones of spring wood and summer wood in the two species of larch was continued. Measurements were made upon butt discs of European larch from Bedgebury, Kent, and from the Forest of Dean, and analysis of the results is in progress.

GRADING OF HOME-GROWN HARDWOODS

The work of the Committee was concluded during the year and a set of simplified rules published[61].

CABLE DRUMS

The work of the Cable Drum Committee on the use of home-grown timbers in cable drums is now completed except for the drawing up of a specification. Drums made from seven home-grown softwood species of grades II and III have been tested in service and all remained satisfactory after being in commercial service for over four years.

VISITORS AND EDUCATION

Visits by individual foresters or persons connected with firms using timber were fewer, totalling 74 compared with 93 in the preceding year. The number of visiting parties was 15, comprising 344 persons in all. There were 89 teachers from three Technical Colleges and two parties organized by the Ministry of Education for Technical College teachers. A party of District Officers and Foresters from the Eastern Conservancy of the Forestry Commission came to study the work being carried out on home-grown timbers. Other Government Departments sent four parties. Three Associations made visits while five other parties, made up mainly from firms predominantly using wood, were shown the work of the various sections.

Visitors from overseas numbered 64, and represented a variety of trades and professions. This year, however, more foresters visited the Laboratory, mainly owing to the greater interest in disposal of thinnings from coniferous plantations.

The number of short courses increased from six to twelve, because of the greater interest of other Government Departments in the technical properties of the timbers they are using.

Forestry students from the Universities of Aberdeen, Bangor, Edinburgh and Oxford visited the Laboratory and the Imperial College of Science also sent students for one day. The total number of visiting students was 107 undergraduates and 9 post-graduates.

There were three seasoning courses attended by 29 students in all.

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F. Y. Henderson,
Director.

Forest Products Research Laboratory,
Princes Risborough,
Aylesbury, Bucks.
January, 1960.

APPENDIX I

STAFF OF THE FOREST PRODUCTS RESEARCH LABORATORY

31st December, 1959

Director of Forest Products Research: F. Y. Henderson, C.B.E., D.Sc., D.I.C., F.I.W.Sc.

ADMINISTRATION

Assistant Director: J. Bryan, M.Eng., A.M.I.C.E.
Senior Principal Scientific Officer: P. Harris, B.Sc.(Eng.), A.M.I.Mech.E.
Higher Executive Officers: J. D. Bingham; R. D. Weeks, M.B.E.*
Executive Officers: S. Calver; Miss D. Lacey*.

SECTION OF WOOD STRUCTURE

Principal Scientific Officers: B. J. Rendle, B.Sc., A.R.C.S., F.I.W.Sc. (Officer in Charge); E. W. J. Phillips, B.Sc., Ph.D., A.R.C.S.
Senior Scientific Officer: J. D. Brazier, B.Sc.
Experimental Officers: G. L. Franklin; D. G. Patterson, M.Sc.

SECTION OF PHYSICS

Principal Scientic Officer: R. F. S. Hearmon, F.Inst.P. (Officer in Charge).
Experimental Officers: E. H. Adams; J. McC. Paton.

SECTION OF SEASONING

Principal Scientific Officer: W. C. Stevens, M.A., A.M.I.Mech.E. (Officer in Charge).
Senior Experimental Officers: R. E. Hodge, Assoc.I.Mech.E.; D. D. Johnston; G. H. Pratt; N. Turner.
Experimental Officer: A. R. Dean.
Assistant Experimental Officer: R. H. Wynands.
Temporary Assistant Experimental Officer: D. C. Bedding.

SECTION OF TIMBER MECHANICS

Principal Scientific Officer: F. H. Armstrong, M.Sc., M.I.Mech.E. (Officer in Charge).
Senior Scientific Officers: A. J. Comben, B.Sc.; W. T. Curry; J. G. Sunley, M.Sc.
Senior Experimental Officer: A. J. Foord.
Experimental Officers: G. R. Brock; W. T. Hide.
Assistant Experimental Officer: S. A. Covington.
Temporary Assistant Experimental Officer: Mrs. W. M. Hudson.

SECTION OF WOOD PRESERVATION

Principal Scientific Officer: D. N. R. Smith (Officer in Charge).
Experimental Officers: R. Cockcroft; Miss E. Lee; D. F. Purslow, B.Sc.; L. W. Redding.

* Retired during 1959.

SECTION OF CHEMISTRY

Principal Scientific Officer: R. H. Farmer, B.A., B.Sc., D.Sc.(Tech.), F.R.I.C. (Officer in Charge).
Senior Scientific Officer: R. A. Laidlaw, B.Sc., Ph.D.
Senior Experimental Officer: D. F. Packman, B.E.M.
Experimental Officer: L. C. Pinion, B.Sc.
Assistant Experimental Officer: G. A. Smith.

SECTION OF MYCOLOGY

Principal Scientific Officer: J. G. Savory, B.Sc., M.Inst.Biol., F.I.W.Sc. (Officer in Charge).
Experimental Officers: E. C. Badcock; Mrs. C. A. Savory, B.Sc.

SECTION OF ENTOMOLOGY

Principal Scientific Officer: J. D. Bletchly, B.A., B.Sc., F.R.E.S., M.Inst.Biol., F.I.W.Sc. (Officer in Charge).
Senior Scientific Officer: M. G. White, M.A., F.R.E.S.
Senior Experimental Officer: E. C. Harris, F.R.E.S.
Experimental Officer: Miss J. M. Taylor, B.Sc., M.Inst.Biol.

SECTION OF WOODWORKING

Principal Scientific Officer: F. H. Armstrong, M.Sc., M.I.Mech.E. (Officer in Charge).
Senior Scientific Officer: K. J. S. Walker, M.A.
Senior Experimental Officers: H. J. Endersby; R. Goodchild.
Assistant Experimental Officer: J. W. Rogers.

SECTION OF EXTERNAL RELATIONS

Principal Scientific Officer: F. G. O. Pearson, B.Sc. (Officer in Charge).
Senior Experimental Officer: A. V. Thomas, M.Eng.
Experimental Officer: Miss C. Webster.
Assistant Experimental Officer: Miss H. A. Fielding, B.A.

SECTION OF COMPOSITE WOOD

Principal Scientific Officer: R. A. G. Knight, B.Sc.(Eng), M.I.Mech.E. (Officer in Charge).
Senior Scientific Officer: J. F. S. Carruthers, B.Sc., A.M.I.Mech.E.
Senior Experimental Officers: L. S. Doman; R. J. Newall.
Experimental Officer: R. W. Hudson.
Assistant Experimental Officer: B. H. Paxton, B.Sc.

SECTION OF PUBLICATIONS AND RECORDS

Senior Experimental Officer: C. J. N. McCracken, B.A., Dip.For. (Officer in Charge).
Experimental Officer: J. A. H. Broughton, B.Sc.
Assistant Experimental Officer: T. Harding.

DRAWING OFFICE AND PHOTOGRAPHY

Senior Photographer: W. J. Baldwin.
Experimental Officer: E. A. Steel, Assoc.I.Mech.E.

APPENDIX II

LIST OF PUBLICATIONS ISSUED DURING 1959

A. STATIONERY OFFICE PUBLICATIONS

Forest Products Research, 1958.

Bulletins:

No. 1 Dry Rot in Wood. By W. P. K. Findlay, D.Sc., and J. G. Savory, B.Sc. (*Sixth Edition.*)

No. 38 The Efficiency of Adhesives for Wood. By R. A. G. Knight, B.Sc.(Eng.), M.I.Mech.E. (*Second Edition.*)

No. 44 Heat Penetration in the Pressing of Plywood. By J. F. S. Carruthers, B.Sc. A.M.I.Mech.E.

Leaflets:

No. 4 The Death-watch Beetle. (*Revised Edition.*)

No. 23 Circular Saws. (*Revised Edition.*)

No. 33 The Bending of Solid Timber. (*Revised Edition.*)

No. 42 Kiln-drying Schedules. (*Revised Edition.*)

Record:

No. 30 The Natural Durability of Timber. By D. N. Smith. (*Second Edition.*)

B. OTHER PUBLICATIONS

ARMSTRONG, F. H. and SAVORY, J. G. The Influence of Fungal Decay on the Properties of Timber. Effect of Progressive Decay by the Soft Rot Fungus, *Chaetomium globosum*, on the Strength of Beech. *Holzforschung*, 1959, **13**(3), 84–89.

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APPENDIX III

REFERENCE LIST OF COMMON NAMES CITED IN TEXT

Abura	*Mitragyna ciliata*
African mahogany	*Khaya* spp.
African satinwood	*Fagara macrophylla*
Afrormosia	*Afrormosia elata*
Afzelia	*Afzelia* spp.
Andaman padauk	*Pterocarpus dalbergioides*
Ash, English	*Fraxinus excelsior*
Ayan	*Distemonanthus benthamianus*
Balsam, Western	*Abies* spp.
Beech	*Fagus sylvatica*
Birch	*Betula* spp.
Birch, Finnish	*Betula* spp.
Camphorwood, East African	*Ocotea usambarensis*
Canarium	*Canarium* spp.
Cedar, Western red	*Thuja plicata*
Corsican pine	*Pinus nigra* var. *calabrica*
Dark red seraya	*Shorea pauciflora*
Douglas fir	*Pseudotsuga taxifolia*
East African camphorwood	*Ocotea usambarensis*
Ekki	*Lophira alata*
Elm, Rock	*Ulmus thomasii*
English ash	*Fraxinus excelsior*
English oak	*Quercus robur* and *Q. petraea*
European larch	*Larix decidua*
Finnish birch	*Betula* spp.
Fir, Douglas	*Pseudotsuga taxifolia*
Fustic	*Chlorophora tinctoria*
Gaboon	*Aucoumea klaineana*
Hemlock, Western	*Tsuga heterophylla*
Indian rosewood	*Dalbergia latifolia*
Iroko	*Chlorophora excelsa*
Japanese larch	*Larix leptolepis*
Japanese oak	*Quercus* spp.
Kapur	*Dryobalanops* spp.
Keruing	*Dipterocarpus* spp.
Larch	*Larix* spp.
Larch, European	*Larix decidua*

Larch, Japanese	*Larix leptolepis*
Loliondo	*Olea welwitschii*
Louro, Red	*Ocotea rubra*
Mahogany, African	*Khaya* spp.
Mulberry	*Morus alba*
Muhuhu	*Brachylaena hutchinsii*
Mumuli	*Holoptelea grandis*
Muninga	*Pterocarpus angolensis*
Munyama	*Khaya anthotheca*
Mushebeya	*Albizzia glaberrima*
Mutenye	*Guibourtia arnoldiana*
Mvule	*Chlorophora excelsa*
Nkoba	*Lovoa brownii*
Nkobakoba	*Baikiaea insignis* subsp. *minor*
Oak	*Quercus* spp.
Oak, English	*Quercus robur* and *Q. petraea*
Oak, Japanese	*Quercus* spp.
Oak, Turkey	*Quercus cerris*
Obeche	*Triplochiton scleroxylon*
Opepe	*Sarcocephalus diderrichii*
Osage orange	*Maclura pomifera*
Padauk, Andaman	*Pterocarpus dalbergioides*
Pine, Corsican	*Pinus nigra* var. *calabrica*
Pine, Scots	*Pinus sylvestris*
Ramin	*Gonystylus* spp.
Red louro	*Ocotea rubra*
Red seraya	*Shorea* spp.
Redwood	*Pinus sylvestris*
Rock elm	*Ulmus thomasii*
Rosewood, Indian	*Dalbergia latifolia*
Satinwood, African	*Fagara macrophylla*
Scots pine	*Pinus sylvestris*
Seraya, Dark red	*Shorea pauciflora*
Seraya, Red	*Shorea* spp.
Seraya, White	*Parashorea malaanonan*
Sitka spruce	*Picea sitchensis*
Spruce, Sitka	*Picea sitchensis*
Sycamore	*Acer pseudoplatanus*
Teak	*Tectona grandis*
Turkey oak	*Quercus cerris*
Walnut	*Juglans regia*
Wawa	*Triplochiton scleroxylon*
Western balsam	*Abies* spp.
Western hemlock	*Tsuga heterophylla*
Western red cedar	*Thuja plicata*
Whitewood	*Picea abies*
White seraya	*Parashorea malaanonan*
Willow	*Salix* spp.

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